~~The Journal of~~
~~the Institution of~~
~~Engineers. (India)~~
~~VOL-9~~
~~1930~~

THE JOURNAL

OF

The Institution of Engineers (India)

INCORPORATED 1920

Edited and Published for the Institution by the Secretary,

8, Esplanade Row, East, Calcutta.

Vol. IX. MAY. 1930.

CONTENTS.

THE NINTH ANNUAL GENERAL MEETING.

The Ninth Annual General Meeting of the Institution was held in Metcalfe Hall, Delhi, at 11 a.m. on Wednesday, 7th November, 1928.

PRESENT :

Mr. H. Burkinshaw (in the Chair).
,, R. D. T. Alexander.
Lt.-Gen. Sir Edwin Atkinson.
Mr. C. Addams Williams.
,, N. J. Cursetji.
,, A. Lines.
,, K. M. Kirkhope.
,, D. G. Harris.
,, A. T. Weston.
Lt. Col. Sir George Willis,
74 Corporate Members
and Mr. F. Powell Williams (Secretary).

PROCEEDINGS.

Mr. H. Burkinshaw took the Chair at 11 A.M.

The Secretary read the Notice convening the Meeting.

The Minutes of the Eighth Annual General Meeting were read and confirmed.

1. The Annual Report of the Council and the Statement of Accounts duly certified by the Auditors were handed to all Members present.

It was proposed by the Chairman that the Annual Report of the Council and Audited Accounts be adopted.

This was seconded by Rao Bahadur V. N. Parulkar and was carried.

2. It was proposed by Mr. K. B. Lal that Messrs. Price Waterhouse, Peat & Co., be re-elected Auditors at a remuneration of Rs. 350 per audit.

This was seconded by Mr. P. L. Dhawan and was carried.

STANDARD SPECIFICATIONS.

The Council have continued to act as the Indian Committee of the British Engineering Standards Association and during the year received a considerable number of Specifications. Details of these have been published in the Bulletins.

INTERNATIONAL ELECTRO TECHNICAL COMMISSION.

The Council have continued to act as the Indian Committee of the International Electro Technical Commission.

JOURNAL.

Volume VII of the Journal was issued and distributed to all Members of the Institution.

BULLETINS.

Bulletins Nos. 18, 19, 20 and 21 were published and issued to Members during the year. The Bulletins contained information concerning the work and activities of the Institution.

ISSUE OF PAPERS.

Mr. F. C. Griffin's Paper entitled "WATER SUPPLY BY DECENTRALIZED STORAGE" was issued to all Members and was read at Meetings of all Local Associations.

EXAMINATIONS.

The first Associate Membership Examination of the Institution was held on the 23rd, 24th and 25th August, 1928 and four candidates sat for the Examination.

AWARD OF PRIZES.

H. E. The Viceroy's Prize for 1926-27 was awarded to Mr. A. Lennox ~~Stanton~~ for his Paper "THE RAILLESS OR TRACKLESS TROLLEY SYSTEM."

Because no suitable Paper was submitted, no award of the prize of £20 offered annually by the Institution of Electrical Engineers was made.

ALTERATIONS TO THE BY-LAWS.

The Council made certain additions to By-law 1 and this was reported in Quarterly Bulletin No. 21 for the information of Members.

LOCAL ASSOCIATIONS.

The Local Associations continue to make progress and held a number of Meetings and Visits during the year.

ACCOUNTS.

The audited accounts for the year ending 31st August, 1928, are appended. The accounts show a deficit of Rs. 3,606-8-8 on the year's working.

The Council consider that after taking into consideration the increased activities of the Institution, the general position is satisfactory.

The Institution of Engineers (India).

Balance Sheet as at 31st August, 1928.

LIABILITIES & SUNDRY CREDIT BALANCES.

	Rs.	A.	P.	Rs.	A.	P.
Capital—						
Permanent Reserve Account.						
Entrance Fees	72,062	5	9			
Composition Fees (for Life Membership) ..	12,719	0	0			
Transfer Fees	1,369	0	0			
	86,150	5	9			
Donation	62,229	10	0			
				1,48,379	15	9
Subscriptions in Advance				1,653	6	11
Suspense				489	14	8
Liabilities—						
For Expenses .. .	408	14	0			
Bombay Association ..	3,764	7	0			
U. P. Association ..	2,869	0	0			
S. I. Association ..	1,673	7	0			
N. W. I. Association ..	1,026	1	9			
Sundry Creditors ..	1,418	12	1			
				11,160	9	10
B. E. S. A. Allowance Fund				2,127	5	3
National Electro-Technical Committee for India				113	6	8
Viceroy's Prize				1,000	0	0
Imperial Bank of India				6,755	10	10
Rs.				1,71,680	5	11

ASSETS & SUNDRY DEBIT BALANCES.

	Rs.	A.	P.	Rs.	A.	P.
Furniture & Fittings—						
As per last account ..	9,169	7	0			
Addition during the year	14	0	0			
	9,183	7	0			
Less: Depreciation @ 5% ..	459	2	9	8,724	4	3
Outstanding (Subscriptions)				7,020	14	11
Sundry Debtors				3,680	14	8
Deposit—						
(Electric Supply Corpn. Ltd.)				25	0	0
Advance—						
Bengal Association ..	2,095	8	0			
D Gestetner & Co .	81	0	0	2,176	8	0
Stock (Stationery & Diploma Papers)				966	9	10
Investments—						
6 10 years Bonds 1930 ..	5,000	0	0			
.. .. .. 1931 ..	42,500	0	0			
.. .. .. 1932 ..	16,000	0	0	63,500	0	0
Alliance Bank of Simla Ltd (In Liqn.)						
On Permanent Reserve a/c ..	5,351	15	0			
On Donations a/c ..	11,771	1	1			
On Suspense a/c ..	5,298	1	4			
	22,421	1	5			
Less: Recovered	14,013	0	8	8,408	0	9
Cash—						
Imperial Bank of India on Permanent Reserve a/c ..	350	11	9			
In hand ..	296	12	3	647	8	0
Income & Expenditure Account—						
Balance as per last a/c ..	72,918	0	10			
Add: Adjustment for last period	6	0	0			
Add: Deficit for the year ..	3,606	8	8	76,530	9	6
Rs.				1,71,680	5	11

We have audited the above Balance Sheet with the Books of the Institution of Engineers (India), and have obtained all the information and explanations we have required. In our opinion such Balance Sheet is properly drawn up and exhibits a true and correct view of the Institution's affairs according to the best of our information and explanations given to us and as shown by the Books of the Institution.

CALCUTTA,
29th September 1928.

PRICE, WATERHOUSE, PEAT & CO., *Chartered Accountants.* } *Auditors.*

The Institution of Engineers (India).

Income and Expenditure Account for the Year Ending 31st August, 1928.

EXPENDITURE.

	Rs.	A.	P.
To Salaries and Wages	34,196	14	7
,, Postage	592	8	0
,, Telegrams	21	10	0
,, Printing	402	4	0
,, Stationery	1,067	2	6
,, Conveyances	40	8	9
,, Rent	2,460	0	0
,, Lighting and Fans	112	7	6
,, Law Charges	19	0	0
,, Journal	1,343	8	0
,, Bulletins	1,470	5	3
,, Annual General Meeting	502	7	9
,, Diplomas	124	2	0
,, Subsidy to Local Associations	8,849	8	6
,, Audit Fees	350	0	0
,, Charges General	354	4	0
,, Telephone	146	0	9
,, Bad Debts	751	0	0
,, Issue of Papers	311	1	3
,, Depreciation	459	2	9
Rs.	53,573	15	7

INCOME.

	Rs.	A	P.
By Subscriptions	45,476	8	0
,, Interest	3,745	1	0
,, Sale of Standard Specifications	740	1	11
,, Sale of Publications	5	12	0
,, Balance being deficit transferred to Balance Sheet	3,606	8	8
Rs.	53,573	15	7

PRESIDENTIAL ADDRESS

BY

R. D. T. ALEXANDER, D.S.O., O.B.E., T.D

PRESIDENT, 1928-29.

GENTLEMEN,

In this Presidential address, the first thing I wish to do is to thank you for the very high honour you have done me by electing me as President of the Institution for 1928-29. This is an honour which I very greatly appreciate and for my part you may be sure that I will do all I possibly can to further the interests of the Institution during my term of office.

My predecessors have, as a rule, on this occasion either addressed this meeting on the activities of the Institution, the training of young Engineers or on some Engineering subject. In my address to-day, I wish to deal in particular with the position and responsibilities of the Local Associations.

The President of an Institution like ours has a great responsibility to shoulder and I feel that the best results cannot be obtained unless he takes members into his confidence and obtains their help continuously. I intend to take you into my confidence to-day and ask you to help to extend the activities of the Local Associations. We must contrive to make all the Local Associations real live organizations and to dispel any ideas of misunderstanding which may exist.

To start with I want you all to realize that the Local Associations are the Institution of Engineers (India) in being and that it is on the success of each and every one of the Local Associations that the success of the Institution as a whole depends. I should perhaps explain that apart from the office where the Secretary and his staff carry out their work, the Institution has no existence except in its Local Associations.

In some Provinces, there is apparently an idea that the Local Associations are not really part of the Institution but are more or less independent bodies attached in some vague but undefined way to the Institution.

I understand that some Local Associations imagine that the funds which they are entitled to receive from the Institution are dependent entirely on their membership and that they should

annually demand a sum of money equivalent to so much per head of their membership.

Neither of these ideas are correct and I wish to impress on you to-day that the Local Association is the Institution of Engineers (India) in that particular Province. Secondly that in so far as it is within the financial power of the Institution, each Local Association will receive that amount of money required for its expenditure during the year—no more and no less.

To facilitate this question of finance, each Local Association should, as soon as possible after the 1st of September in each year, send to the Secretary of the Institution a budget of their proposed expenditure. This will be considered by the Council and, if passed, then the money will be allotted to that Local Association. You will, however, realize that it would be bad finance for the Institution to transmit a considerable sum of money to the Local Association until it is actually required.

I should like to point out that at present the annual expenditure of the Institution is from Rs. 6,000 to Rs. 7,000 in excess of the money it receives. So far we have been working on overdraft against our reserve and I feel sure that you will agree that it would be bad finance to send to each Local Association a lump-sum of money at the beginning of the year and thereby increase our overdraft on the bank on which we have to pay interest. I therefore suggest that this difficulty can best be got over by the Local Associations working on an Imprest Account which will be recouped from time to time as may be required. I trust that I have made the two points clear, viz:—

(1) That the Local Associations are the Institution of Engineers (India) in their respective Provinces.

(2) That the money which they are entitled to receive should be equivalent to their approved expenditure and no more and no less. No Local Association should at the end of a year have either a credit or debit balance.

I hope that I have cleared up these two points and now let us see how we can improve the activities of the Local Associations.

I know from experience that the general failing of all men is to put on to the busiest man any extra work that is going. Honorary Secretaries of Local Associations are not apparently exempt from this failing of their fellows and we usually find that the Honorary Secretary of a Local Association is one of the hardest worked men in the Province. It is very difficult indeed for any one who has to work long hours in his own sphere of activity to

devote the time necessary for carrying on efficiently the work required from an Honorary Secretary of a Local Association and I think it is asking an impossibility unless efficient help be given to that gentleman who consents to take on these duties. As I have already said the Local Associations are the Institution of Engineers (India) in being and it is of vital importance that everything possible be done to give those Local Associations a reasonable chance of performing their share in the organization. The correspondence necessary to do this is very great and is in my opinion overwhelming for any one who has other duties to perform unless he be given efficient assistants. I therefore think it advisable that each Local Association should, in addition to the Honorary Secretary, have a paid well-educated Head-clerk who will be able to do the routine work and thereby give the Honorary Secretary time to plan arrangements for increasing the efficiency and popularity of the Local Associations.

You may think that the above remarks are rather on the lines of a sermon but I can assure you, gentlemen, that I have the interests of the Institution very much at heart and I feel that if we are to take our place amongst the great technical institutions of the world, we have to make a really serious effort now and that effort must be made by each of the Local Associations.

In connexion with this matter I would remind you that one of the greatest difficulties with which our Institution has to contend at present is that of finance. You have seen the balance sheet and you all know that our annual income does not meet our expenditure. There are two ways of remedying this:—

(i) By raising the annual subscription

and

(ii) by obtaining increased membership

I think it would be a very retrograde step indeed to raise the annual subscription but I do feel that there is considerable scope for increasing our membership. I am not for one moment suggesting that the standard of admission to the Institution should be lowered in the very least degree but there are many Engineers in India who are fully qualified and who do not at present belong to the Institution. These Engineers in common with those who belong to the Institution obtain their livelihood by work in India and it is surely their duty to support the Institution which has done so much to foster engineering interests and to maintain engineering standards in this country.

I am sure that every one of us here knows several qualified Engineers who do not belong to the Institution and I would

therefore ask you to point out to these gentlemen what they are missing by not belonging to it and the path in which their duty lies.

I do not wish you to think that I am asking you to beg people to join the Institution, but what I do ask you is that you will tell your qualified Engineer friends about the Institution and let them know the advantages to be gained by both themselves and by India as a whole if they come forward and join. I am perfectly certain that the reason why those qualified Engineers who are not members do not belong to the Institution is that they have never been told anything about it. If each of you will help me by shouldering a little of the work, the Institution will, in a short time, be in a very flourishing condition indeed. Please however keep this uppermost in your minds—the Local Associations are the Institution of Engineers (India) in being and if each is a real live organization, then the Institution as a whole will fill the part for which it exists.

THE NINTH ANNUAL DINNER.

The Ninth Annual Dinner of the Institution of Engineers (India) was held in Maidens Hotel, Delhi, on Friday 9th November, 1928.

Mr. R. D. T. Alexander, Chief Engineer, Bengal-Nagpur Railway, President of the Institution, presided. His Excellency the Viceroy honoured the Institution by his presence. The guests included the Hon. Sir Bhupendra Nath Mitra, the Hon. Mr. A. C. McWatters, Mr. P. C. Sheridan, Sir John Thompson, Maj.-Gen. A. G. Stevenson, Mr. G. Cunningham, Mr. A. A. L. Parsons, Mr. T. G. Russell, Mr. E. J. Buck, Mr. K. C. Roy, Mr. P. Mukerjee, Mr. U. N. Sen, the Hon. Mr. E. Burdon, Mr. A. M. Rouse and Mr. T. Ryan.

His Excellency the Viceroy proposed the Toast "The King-Emperor."

The President in proposing the toast of "the Health of His Excellency the Viceroy" said :—

Your Excellency and Gentlemen,

I find it difficult adequately to express our pleasure at the honour which Your Excellency has paid the Institution of Engineers (India) by being our guest to-night.

The Institution was founded in 1919 and His Excellency Lord Chelmsford honoured the inaugural meeting with his presence. Since then succeeding Viceroys have always taken an interest in the Institution and in addition have been good enough to present a prize for the best paper read during the year. I may say, however, that the activities of the Institution are not solely confined to the maintenance of the machinery necessary for the award of the Viceroy's prize however much this prize is appreciated.
The main objects of the Institution are :—

(1) To maintain the high standard of the Engineering profession in India.

(2) To create a standard for the guidance of Students who are under training to become Engineers.

(3) To afford a means by which Engineers possessing special knowledge on various subjects can transmit this knowledge to others by the reading and discussion of papers before the Institution.

India is a large country and it is obvious that an Institution located in one centre can do very little good to the country as a whole. In consequence a scheme was devised by which the Institution of Engineers (India) would be represented by Local Associations in each of the great Provinces. These Local Associations are therefore the Institution of Engineers (India) in being and it is on them that the usefulness and the prosperity of the Institution depend.

We all know that Your Excellency takes a great interest in agriculture and India is, probably more so than any other country in the world, dependent on agriculture. Extensive agriculture however cannot well be undertaken in a tropical country unless means are provided for bringing water to the land and for transporting the surplus grain when it is grown and so the agriculturist is in turn dependent on the Engineer.

I feel that Your Excellency is one of the very first to realize this fact and by the interest which you have taken in the great Engineering Works at present going on in India, the Engineers employed on those works have certainly been stimulated to greater efforts.

It was only a few months ago that Your Excellency visited the new Port being constructed at Vizagapatam. I know from first hand information the stimulus which that visit gave to the work there and perhaps I will not be saying too much if I mention that last year when 11 miles of the Bengal-Nagpur Railway Main line between Calcutta and Madras was wiped out of existence by the abnormal flood of the Bytarani river, the fact that trains ran between Calcutta and Madras within 7 weeks of the disaster was due very largely to the personal interest which Your Excellency took in the labours of the Engineers to get the line through.

In the past India was very largely dependent for her Engineers by recruitment from Great Britain. This state of affairs no longer pertains to-day. We now have in India several Colleges and Universities where young men of the country can be efficiently trained as Engineers, and I am pleased to tell you that so far as my experience goes, the majority of these young men have made good but it must be recognized that as the Engineers at Home look to the great Engineering Institutions of the country, so must the Engineers of this country look to the Institution of Engineers (India).

The interest which Your Excellency has shown in our Institution will do much to foster this idea and will have very far-reaching effects in assisting this Institution to take its place amongst the great Engineering Institutions of the world.

On behalf of the Council and the Members of the Institution of Engineers (India) I wish most heartily to thank Your Excellency for sparing the time to attend our dinner to-night, especially as I know how very fully occupied Your Excellency is at the present time.

I hope however that in years to come when you hear of the prosperity and the power of the Institution of Engineers (India), you will look back to-night and feel some little satisfaction in knowing that the turning point in the career of the Institution was due to the interest and help which you have shown to it.

Gentlemen, I will ask you to charge your glasses and drink with me the health of His Excellency Lord Irwin The Viceroy and Governor-General of India.

His Excellency the Viceroy in reply to the toast of his health said :—

It has not seldom been my experience, when an engineer is endeavouring to explain to me the intricacies of his pet project or machinery, to feel acutely the limitations of my knowledge compared with his. If that be the effect produced on me by one of your number, you can imagine the frame of mind in which I rise to address a whole room full of the fraternity. But I can at any rate thank you all without reservation for your hospitality in entertaining me here to-night, and I need hardly say how great a pleasure it has given me to meet so many members of the Institution of Engineers in India. I should also like to thank you, Mr. President, for the very kind things you have said this evening, and the whole company for the way they have received the toast of my health.

I have thought always that engineers were much to be envied. For one thing, they are among those lucky people who have been able to dream dreams in boyhood and realize them in after-life—for every right-minded boy's ambition is to be an engineer, though he may not always foresee the years of exacting training which an intricate and technical science like this requires.

For another thing, the engineer can see with his own eyes the visible results of his work. Many of us laymen, especially if we have at any time had the misfortune to be politicians, must often feel inclined to ask ourselves what has really been the outcome of months or years of laborious work. We cover pages of paper with argument and reasoning and conclusions, or spend our best efforts

in making speeches, which rarely are as convincing to our audiences as they seem to be to us, but when we look later on for tangible results, that we can point to, we begin to wonder what is the sum total of our achievement. The wheels of administration move slowly; much of what we seek to do is inevitably the second best; and the world is more ready to accord criticism than approbation. We deal with opinions, you with facts; and your pages of figures and calculations bring concrete results in the shape of bridges, railways, canals, machines. You can see the girders rising, the water flowing, the two shining lines of metal stretching away over the plain and vanishing into the horizon, and, as you survey your work, you can see that it is good.

It is true that most of the great engineering feats in India have been performed by engineers in the service of Government, but as industry expands, as in the course of nature it must, India will more and more feel the need of qualified engineers, whether in Government service or not. And it is here that your Institution has its function to fulfil. Public bodies and private firms will, if they are wise, always demand engineers whose qualifications are known to conform to certain standards, and an Institution such as yours is the best means of assuring the maintenance of those standards. And more than this; men find in such an Association as this a stimulus to their work. Added to the natural pride which any good craftsman takes in his work, is the corporate pride he feels in maintaining the traditions of the body to which he belongs. The more jealously you guard those traditions and the more rigidly you insist on the maintenance of high standards and the good name of your profession, the more valuable will your Institution be both to its own Members and to the community at large.

As you have just said, Mr. President, it is now nearly eight years since Lord Chelmsford inaugurated your body, and in doing so he forecast a great and successful future for it. I am very glad to know that it is fulfilling his prediction. Its membership of well over 1,000, from all branches of the profession and in all stages of their professional career, and the formation of Local Associations in every quarter of India, are sufficient proof that it has established its position and are a good omen for its further increase in the future.

And what is the future going to bring in the engineering world? It is a commonplace that the advance made in engineering and mechanics within the memory of this generation has probably exceeded that made in any equal period before in the history of the world and a modern writer has told us that, during the last 150 years, the rate of progress in man's command over nature has

been ten times as fast as in the whole period between Cæsar and Napoleon.

The pace is tremendous, the effect of change in almost every sphere of life kaleidoscopic, and I sometimes wonder whether we can exactly foresee the effect of all this upon human character and temperament.

Many years ago, Samuel Butler if I remember rightly, levelled a lance against the gradual and as he thought sinister domination that the machine was bound to establish over the man who had called it into being. Since he wrote, our whole conceptions of time and space are in course of being recast under the influence of modern invention and discovery, and here as in the evolution of industry under the influence of the machine there is some room for Butler's doubt whether man is in fact retaining control over the new forces his ingenuity has released. In any case we can hardly suppose that, when his whole environment is undergoing transformation, man himself will remain constant and unaffected. I was interested to notice, in the speech that Sir Alfred Ewing made at the Centenary celebration of the Institute of Civil Engineers in London last June, reflections not unconnected with those to which I have endeavoured to give expression. The subject of his address he termed "a century of inventions," but, after sketching the amazing progress made in the last 100 years, he asked himself whether that progress had not outstripped the ethical progress of the race. He spoke of the Great War and how that brought home to him what he termed "the moral failure of applied mechanics." But it was not a note of pessimism that, I think, he meant to strike but rather one of inspiration for the future. We may admit that great as the impetus was which the Great War gave to engineering and scientific inventions and research, it was largely an impetus in a destructive direction. Seen from this angle, with full recognition of all that was good in the concentrated effort of the War, the contemplation of the highest scientific genius of man employed upon the destruction of his fellows was not an inspiring spectacle. It was not progress in the sense in which thinking engineers imagine the true development of their profession. You would all, I know, agree that the victory which engineering and science has achieved over inanimate nature is no real triumph unless that triumph is employed and developed for the benefit and greater happiness of mankind. This must be at once the goal and the test of our endeavour.

You were good enough to refer, Mr. President, to the interest I have always taken in the efforts of engineers, whether in India or elsewhere, to develop the country and improve the conditions and amenities of its inhabitants. Well, during the last two and a

half years I have travelled pretty widely over India and have seen visible and unforgettable proofs of what engineers have done for the people of India, how canals and railways and other means of communication have secured great tracts from the old terrors of famine, how the desert has been made to blossom, how the lot of the poor has been improved, how wild tribesmen have been tamed, how health has been brought to fevered districts, and new comforts of life to dwellers in the remotest parts. And for this, among other reasons, I rejoice to see engineers joining together in an Association like this, whose tendency will surely always be to direct the science of engineering along beneficent lines.

I thank you, Gentlemen, again for having permitted me to be your guest, and I should like to assure you once more that I shall retain thereby a more direct and personal interest in the future growth and fortune of your Institution.

The President in proposing the toast "Our Guests" said :—
Your Excellency and Gentlemen,

As an engineer, I would as a general rule prefer to build a Railway than make a speech, but when the speech concerns our guests the matter is very different and it gives us all very great pleasure to welcome the distinguished company of guests whom we have here to-night. In this great Imperial City of Delhi one naturally expects to meet distinguished people but we realize that the greater distinction a man obtains the greater are the calls on his time and so we feel ourselves indeed fortunate that so many of our friends have found it possible to come to-night.

We are glad to see amongst us again our old friend Sir Bhupendra Nath Mitra, at present Member of Council for Industries and Labour. The services which Sir Bhupendra Nath Mitra rendered to the Empire as Controller of War Accounts are well known to all of us and the work entailed in connexion with that task must, even for a giant of finance like him, have been beset with difficulties no less in their own way than the mud of France or the deserts of Mesopotamia were to the soldiers. We, however, heard nothing of Sir Bhupendra's difficulties, all we knew was that in a very short time after the War was over those who raised questions of back-pay were politely but firmly informed that the accounts were closed and the question could not be re-opened.

Gentlemen, Sir Bhupendra Nath Mitra has recently been acting as Financial Member and controlling the finances of this huge country which is a colossal task. Some idea of the versatility and ability of our guest may be gathered from the fact that at the country's need he smilingly turned from Industry and Labour to Finance and remained undismayed.

It is a great pleasure to us to welcome the Hon'ble Mr. A. C. McWatters, Secretary of the Department of Industries and Labour, who is so closely allied to the engineering profession, in that, Industry is based upon engineering and without labour all engineering work would be at a standstill. We feel sure that Mr. McWatters realizes probably better than any one else in India that to obtain the best work one must also maintain that feeling of good will and good fellowship between employer and employee which is so essential to success.

We feel greatly honoured in having such a strong representation of the Railway Board amongst our guests to-night. We all know how much the Railway Board have done and are doing for the development of India. It is to them that we owe direct rail communication between the North and South of India and also into many parts of the country which only a few years ago were considered as inaccessible except for somewhat primitive means of transport and with their enterprise and zeal it is hoped, that we may yet see Burma in rail communication with India, and Jeypore and Bastar, with the seaports of Madras.

We have had the pleasure of entertaining Mr. Sheridan once before and we are all sorry that by the time our next annual dinner comes round he will have retired from India and we will have lost his cherry optimistic presence amongst us. He will certainly carry with him our good wishes and those of a very large circle of friends.

Mr. Russell attends this meeting as a guest for the last time, not because we do not love him, far from that, but he is an engineer by profession and much as we like to have him as a guest I am glad to say that in future years he will attend as a host as he is about to become a member of our Institution thus following in the footsteps of the Chief Commissioner of Railways, Sir Austen Hadow, and of his predecessor, Sir Clement Hindley who was President of the Institution and whose activities are now, to India's loss, transferred from Simla to Epsom and from trains to Totes.

Mr. Parsons, the Financial Comissioner, represents the one great force in nature which engineers know from bitter experience is beyond their control. Gentlemen, he holds the purse strings, and even the buffalo of Bastar or the bison of Jeypore will not induce him to release them until he can clearly see that percentage yield demanded by the tax-payer—whom he must ultimately face himself. It says a great deal for the genial personality and tact of our guest that he can cut down a Budget without shattering the hopes of those who prepared it.

We are specially glad to welcome to-night Sir John Thompson, Chief Commissioner of the Delhi Province. On behalf of the Institution I wish to take this opportunity of thanking him for his

great assistance in helping the members of the Institution to see the works which are going on in this great city.

We are also glad to see Major-General Stevenson, Engineer-in-Chief, Army Head Quarters. Many of us here to-night have had the privilege of serving during the War with the famous corps of Royal Engineers of which General Stevenson is now the Engineer-in-Chief in India. To entertain such a distinguished member of the Corps provides a happy occasion for the welding of another link in the chain which binds the Military and Civil engineer.

We very much regret that at the last moment Rai Bahadur Lala Moti Sagar, Vice-Chancellor of Delhi University, found it impossible to attend to-night. The Institution of Engineers is fully alive to the fact that a high standard of education in India is essential for the progress of the country. We realize that the high standard which we have set can only be maintained if succeeding generations of recruits receive their preliminary training in Institutions such as the Delhi University which is at present so ably guided by Rai Bahadur Lala Moti Sagar.

Mr. P. Mukherjee, Chairman of the Punjab Chamber of Commerce, has done much to forward the prosperity of India and we are proud to feel that he could spare the time to come here to-night. We particularly realize that our guest represents the culmination of our engineering efforts because Commerce and Industry in these days are based almost entirely upon efficient machinery or other engineering works.

To Mr. Buck, Mr. K. C. Roy, Mr. Sen and our other friends of the Press we extend a very hearty welcome. The Press have at all times supported and encouraged us by a whole hearted appreciation of our efforts and the publicity which they have always so generously given to the work of the Institution has proved of the greatest value in furthering its aims and objects and I would like to take this opportunity of thanking them for what they have done.

Lastly we extend a hearty welcome to Mr. Powell Williams, our energetic Secretary, who has always been our guest on this occasion. We are glad to see that he has now completely recovered from his recent serious illness and is fit for another spell of strenuous service.

Well, gentlemen, I will not detain you longer. I will now ask you to drink the health of our guests coupled with the name of the Hon'ble Sir Bhupendra Nath Mitra.

Sir Bhupendra Nath Mitra, in reply, said :—

Your Excellency, Mr. President and Gentlemen,

On behalf of myself, and of all those who are your guests to-night, I thank you most heartily both for your hospitality and for

the very kind way in which you have received the toast of our healths.

I consider it a great misfortune that I am not an engineer. At the same time, I have claims to close affinities and associations with that worthy body of men to which our hosts belong. My father was an engineer and one of my brothers beat all previous record at Rurki. The portfolio which I have the honour to hold at the present moment includes the administration of the Public Works Department of India, the Indian Telegraph Department and the Indian Stores Department, and the ex-officio Chairmanship of the Committee directing the operations connected with the construction of the New City of Delhi, which, I understand, you have been visiting yesterday and to-day. As Controller of War Accounts and Financial Adviser, Military Finance, I was brought into close touch with military engineers and their civilian colleagues whom the needs of the Empire had diverted temporarily into military employ, and I had the advantage of seeing some of their splendid handiwork in the roads which traverse Waziristan and in the railways, roads and harbour-works in Iraq. And in these capacities, and subsequently as Finance Member, I have had opportunities of viewing the activities of the profession from other than the purely utilitarian angle.

In the result, I can say without hesitation that the engineering profession has no greater admirer than myself. There is always a fascination clinging to the exceptionally large, and this applies particularly to the vast scale upon which the engineer works, whether he is building a new city, constructing a new railway, excavating a new canal, or merely exceeding an estimate!

It has been a great pleasure both to me and to my fellow guests to meet you here collectively this evening and to have this opportunity of expressing our thanks not only for the entertainment provided but for the many material benefits which we owe to your profession. I sometimes wonder, indeed, whether the average layman realizes sufficiently how greatly the whole progress of civilization depends upon the engineer. Without him, we should have no transport; no ships, no harbours, no railways, no canals, no roads, no motor cars, no aeroplanes. Communication, as we understand the word, would cease; there would even be no telegraph and no cheap post. Human habitation would be confined to the immediate vicinity of a perennial source of water. Almost every commodity we use, the paper we write on, the pens we write with, the books we read, our daily paper—even if it may cost us only an anna—depend, for production on such a scale as to make them generally available, upon the art of the engineer. Without him, the very houses in which we live, the food which we take from day

to day, and the clothes which we wear, would be something very different from what they actually are.

Nor is there, perhaps, any other profession to which we extend such implicit confidence as we do, often perhaps unwittingly, to the engineering profession. Every day, and many times a day, we stake our lives upon the integrity and professional ability of the engineer. It requires but a slight error in calculation to render a bridge unsound, a foundation unstable, a machine unsafe, and it is to the everlasting credit of the profession that so few mistakes are made and that accidents are so rare as they are.

Recent experience during the Great War has also demonstrated forcibly how great and important a part is played by the engineer of various classes in defending our hearth and home against the aggression of foreign enemies. It is hardly necessary for me to dilate upon this subject as everyone is aware of the wonders which were achieved by the engineers upon every front. Indeed, although it may sound somewhat of a back-handed compliment, it may safely be said that without the engineer, both mechanical and civil war on the modern scale would be entirely impossible.

But, if the engineer has great responsibilities he has also his compensations. He is one of the few who has the satisfaction of really seeing his own achievements and of leaving a material monument behind him. Many of us must have envied the feelings of the engineer on the completion of some great work which he has himself designed and built—the knowledge that, for generations to come, it will stand as a lasting and beneficial memorial. In very few walks of life is this satisfaction vouchsafed. The picture has, of course, its other side. The mistakes of the administrator may not be patent to the man in the street, and the doctor can bury his, but the engineer's mistakes are perpetuated in steel or stone. It is, however, as I have said, to the credit of the profession that such mistakes are so very rare.

The immense value to the community of the services of the engineer makes it obvious that an institution which is intended to bring together and to facilitate the exchange of ideas among engineers from all parts of India and of various branches of the profession, civil, mechanical and electrical, must be a very powerful influence in the development of the country, and that its meetings must be matters of far more than local importance. On behalf of myself and my fellow guests. I again thank you heartily for the invitation which has given us the opportunity of meeting you all to-night.

Maj.-General A. G. Stevenson in proposing the toast "The Institution" said :—

Your Excellency, Mr. President and Gentlemen,

I find myself somewhat at a disadvantage in bringing to your notice the toast which has been allotted to me owing to my want of personal knowledge of Indian engineers and engineering as I have only been five months in the country.

I naturally follow with interest the accounts in the Press of the opening of large engineering projects in this country and of these I think the most recent one is the Lloyd Dam in the Bombay Presidency. I do not propose to quote the statistics of its capacity or its dimensions but I understand from the Press it is the biggest thing of the kind on earth and that you have the U. S. A. beat to a frazzle ! Whether the above claim is tenable or not is neither here nor there but there is no doubt that an extraordinary finely conceived and executed engineering project has been carried out. Following on the achievement the engineering staff concerned have received public awards and doubtless private congratulations from the Members of this Institution and I am sure that in addition the engineers rightly feel that they are entitled to pat themselves on the back for they have seen the work of their hands and it is good.

Looking back upon the years that have elapsed since the inception of this project the engineering staff must call to mind the early days of reconnaissance, collection of meteorological data, levelling, the test of foundations, the design calculation and specification of the structure, the preparation of estimates and the battle with the financial branch to get these sanctioned. Then followed the constructional period with all its delays and worries great and small from the non-arrival of vital materials to the bites of the ubiquitous sandfly. Over the entire period is spread the recollection of the team work of the staff, the *esprit de corps* of the engineers, and we finally come to the ending of anxiety and responsibility with the knowledge that no chinks have been left in their armour and that there is no danger of failure of the greatest dam in India and I believe the world.

Looking at the picture which I have tried to sketch out for you, you will appreciate that to carry out a large engineering feat of this nature successfully and economically requires that those in charge must be qualified by suitable training and experience and possess personality. This latter quality is present in all of us to a more or less degree but it is undoubtedly strengthened by the confidence which comes from knowing your job outside and in and thereby gaining in your turn the confidence of your seniors and subordinates.

When one turns to the constitution of this Institution it is evident that all the necessary factors for making such engineers have been legislated for. The embryo engineer is caught young and his general educational qualifications are scrutinized. He presents himself for his professional examinations as Student and Associate Member and in process of time and experience becomes a Member. All these years he has had the advantage of the meetings, publications and intercourse of the Institution to help him by the interchange of views. He has the backing of the Institution in all things affecting his profession.

I think it may then be taken that the Institution of Engineers (India) is a worthy means of fostering the science of engineering in all its branches in this great country. I trust its members may always be fully employed and judging from the scope which exists in this country I do not think there is any doubt that they will.

Your Excellency, Mr. President and Gentlemen, I ask you to rise and drink success and prosperity to the Institution of Engineers (India).

Lt.-Col. Sir George Willis in reply said :—

Your Excellency, Mr. President and Gentlemen,

General Stevenson in happy phrase has impressed on us as representative of the profession in India the great importance of co-operation between engineers.

In assuring him that this is a matter which the Institution has very closely at heart I speak not for myself but for all our Members. As perhaps our guests may not have noticed, but as we are all well aware, India, taught by time, has taken one step in advance of the profession at home where there are separate Institutions for different branches of engineering with what is now very generally thought to be a great dissipation of energy and funds and a lack of cohesion. Our Institution is all-embracing and consequently co-operation is more easy of attainment than it would otherwise be.

I will not enlarge further on this matter but will ask your attention to a point of very great interest to us as Members and, did India but know it, of very great interest and importance to the country. I refer to the rapid growth of the Institution in numbers.

A little while ago I heard from our first President, Sir Thomas Ward, who wrote regarding what I said at the Annual Dinner in

Bombay in 1927 about the increasing usefulness of the Institution to India. He sent me a report of the American Society of Engineers and from this it appears that it took that Society forty years to reach the numerical strength we have attained in eight.

Despite the advantages we have over the American Society in the very great increase in the numbers of qualified engineers since the time when it was founded, yet we may congratulate ourselves very heartily on this rapid growth. We now number well over 1,000 of whom more than 850 are Corporate Members, though we have lately removed from our lists the names of those few who had failed to keep up their payments. The increase has not been attained by going out into the highways and byways for we have always been careful to maintain with the utmost strictness the high qualifications which our constitution requires in successful recruits.

Having now patted ourselves sufficiently on the back we must turn our attention to our further duties to the Institution. Growth of numerical strength, though important, is not our sole object or even our main object. We must aim at continuous growth in influence resulting from the ability and readiness of the Institution to help, in every way connected with the profession of engineering, the country whose name is included in our title in the first place and secondly our members, associates and students.

To that end it is not sufficient merely to join the Institution and pay subscriptions regularly. Much more is necessary than that. Every Corporate Member who is worth his salt must take a real interest in the work and the success of the Institution. Refer to the Institution in your difficulty. Refer others to the Institution when they are in difficulty. If you are doing interesting work let us all know about it. There is a paucity of papers on engineering subjects. Short pithy papers will be greatly welcomed.

There are other ways in which members can help their Institution. Think them out for yourselves. If we all did 1/365th of the boy scout's duty to his Institution and did one good deed a year for our Institution, it would be the most flourishing professional organization in the world. Over eight hundred good deeds every year, not counting those which we hope and trust will be performed by the Governments and the public of India in whose benefit and interest it is, as much as in our own, that our Institution should go on and prosper.

COOLER HOUSING

BY

F. R. MORGAN, Member.

1. The ideas in this paper and the experiments on which some of it is based were conceived and carried out more than twelve years ago. A year or so later an article on Cooler Housing was written but never completed. It remained buried in a file until dug out for the purpose of preparing this paper, which is put forward in the hope that there might be something in it that others might develop for the amelioration of hot weather conditions in the Tropics. The paper in most part aims at indicating lines along which study, thought and experiment might prove useful in the quest for cooler housing.

2. The sun is our source of heat. If we stand in its rays we absorb heat and feel hot. If we interpose something between us and the Sun, an umbrella, a tree, a roof, for instance, we absorb less heat and feel less hot, the degree to which we feel less hot depending on the material, the size, the colour, the thickness and other properties of the thing interposed. If we place different materials in the Sun, or the same materials differently surfaced, coloured and, perhaps, shaped, we find differences in the rates at which they absorb the heat of the Sun's rays. We find, also, that when the rays of the Sun are cut off from these materials they cool down differently, some cooling more slowly than others.

3. Every school-boy knows that India lies wholly North of the Equator, and if we look at a map of India we find that the whole of Northern, which is about half of India, is situated North of the Tropic of Cancer. We haven't to go to school to learn that the winds that prevail practically everywhere in India blow mostly North or South being connected as they are with the Monsoons which are so marked a feature of the Indian

climate. If we begin to think about ways and means of improving hot weather conditions we shall note all these things.

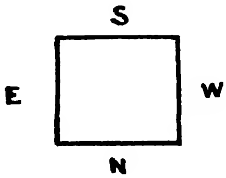
4. The Tropic of Cancer, we were taught in school, if I remember rightly, marks the Northern limit of places on the face of the Earth where the Sun appears perpendicularly overhead during some portion or portions of the year. Places North of the Tropic of Cancer *never* have the Sun overhead, the Sun in its passage across the Heavens travelling in a plane which is inclined to the South, the degree of inclination depending on the time of the year and the latitude of the place of observation North of the Equator. The significance of this to the designer of cooler houses in India is that in the portions South of the Tropic of Cancer, only for a short time every year does the Sun ever shine on the North side of a house, between the hours of 6 a.m. and 6 p.m., but in the portions North of the Tropic of Cancer, the Sun *never* shines on the North side during the 12 warmest hours of the day.

5. The orientation of dwelling houses so that one face faces due North is a common practice in most parts of India. Engineers have practised it for very many years. But in New Delhi, architectural requirements, so one was given to understand, caused the location of most, if not all, of the houses with their main axes parallel to the roads that they faced. As the angles between adjoining roads in New Delhi are 60 degrees, only one-third of the roads can run North and South and of rectangular houses only those facing these roads can have faces on the North or South. Thus only one-third of the houses can be sited in the manner that the experience of years taught the engineers was best. These wrongly facing houses are not among the coolest in New Delhi.

6. In Northern India the orientation of dwelling houses so that the major axis runs East and West gives two tangible advantages to such houses, the first being the greater capacity of the buildings for catching the prevailing breezes, the second being the ability to provide large and cool North verandahs for general living purposes. But there appears to be another advantage which has not had the same consideration. That is the disposition of the mass of the building in the best manner to resist absorption of heat from the direct rays of the Sun. This is worth considering.

7. Let us look at a few examples. Take, for instance, a square house placed four-square to the points of the compass. We need only consider the Sun between the hours of 6 a.m., and 6 p.m.

We will imagine, for convenience of calculation, that the Sun moves in a horizontal instead of in an inclined plane; then



(i) the East wall would be shone upon from 6 a.m. to 12 noon = 6 hours

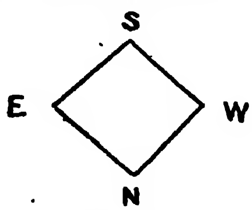
(ii) the South wall would be shone upon from just after 6 a.m. to just before 6 p.m., or just under = 12 „

(iii) the West wall would be shone upon from 12 noon to 6 p.m. = 6 „

Let the length of the wall be a and the height = h then the area of the wall = ah and the number of hours the walls are shone upon multiplied by the areas of the walls in terms of ah will be the number of Sunlight Area Hours (abbreviated SAH) of the house. But as h will be the same in all the figures to be considered it may be omitted and the term a accepted as equal to ah.

Then SAH for the above square building of side a placed four square to the points of the compass =6a+12a+6a=24a.

8. Take the same building and place it with its corners to the points of the compass. As before consider SAH for rays in the horizontal plane.

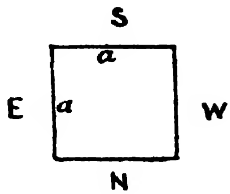


Then SAH for	N.E.	wall	=	3a
„ „	S.E.	„	=	9a
„ „	S.W.	„	=	9a
„ „	N.W.	„	=	3a.
		Total		24a

9. Thus it appears that for rays travelling round in a horizontal plane there is no difference in the SAH whether the sides are placed foursquare to the points of the compass or to the half points. If the building were circular it would be easy to see that all day long rays moving round in a horizontal plane would keep half the circumference in sunlight. Any other evensided regular figure would be the same and we may take it that considering horizontal rays we need not give much consideration to the orientating of our building.

10. But the Sun's rays are never horizontal and in Southern India they are more nearly vertical. A few figures might be considered for SAH with reference to rays travelling in a vertical plane. For convenience of distinction vertically considered Sunlight Area Hours may be abbreviated VSAH and horizontally

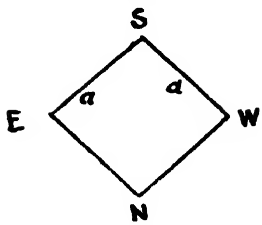
considered SAH abbreviated HSAH. Take the following few cases :—



(i) Square, side = a, sides facing N, E, S, and W.

HSAH $= 24a$

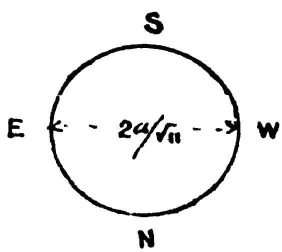
VSAH $= 6a + 6a = 12a$



(ii) Square, side = a, sides face NE, SE, SW and NW.

HSAH $= 24a$

VSAH $= 2 \times 6a + 2 \times 6a = 12a + 12a = 24a$

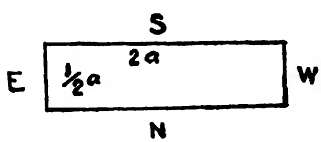


(iii) Circle, area $= a^2$, diam $= \frac{2a}{\sqrt{\pi}}$ circumference $= 2a\sqrt{\pi}$. Half the circumference would always be in sunlight both horizontally considered and vertically and

HSAH $= 12a\sqrt{\pi} = 12 \times 1{\cdot}772a = 21.26a$

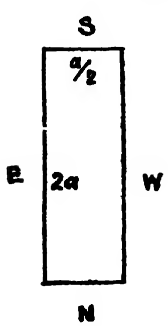
VSAH $= 12a\sqrt{\pi}$,, $= 21{\cdot}26a$

(iv) Rectangle, area $= a^2$, lengths of sides 2a and ½a, long axis running E. and W., i.e., the long sides facing N. and S.



HSAH $= (6 \times \frac{1}{2}a) + (12 \times 2a) + (6 \times \frac{1}{2}a) = 30a$

VSAH $= (6 \times \frac{1}{2}a) + (6 \times \frac{1}{2}a) = 6a$



(v) Rectangle as above, area $= a^2$, lengths of sides 2a and ½a, long axis N. and S., i.e., long sides face E. and W.

HSAH $= (6 \times 2a) + (12 \times \frac{1}{2}a) + (6 \times 2a) = 30a$

VSAH $= (6 \times 2a) + (6 \times 2a) = 24a$

The last two examples, as far as the rays considered vertically are concerned, appear to demonstrate the importance of the correct orientation of a shape.

11. It might be objected that this paper appears to treat all hours of Sunlight as equally warm or equally warming whereas they are nothing of the sort. That they are not and what their progressive value is remains to be determined, but it must be remembered that if the morning and evening rays may be considered cooler than the midday rays, the morning rays play on cooler and therefore more absorptive walls, and though the South wall, which appears to be the controlling wall, is shone upon for twelve hours of daylight the average heating effect per hour on this wall should not be greatly different from the average heating effect per hour on the East and West walls which are each shone upon for six hours at a time.

12. Of course the amount that heat rays would heat an actual substance would depend on the angle or angles at which they impinged on the surface of the substance, but for purposes of our comparisons it would seem right to assume total absorption from the beginning, that is that the angle between the rays and the plane on which they impinge at which total absorption takes place $=0°$

13. The mathematics that would be involved in working out the SAH for rays travelling in a plane inclined to the horizontal, the angle varying with the latitude and the time of the year would be somewhat complicated and the writer does not see any great need for it, preferring to work out any given cases horizontally and vertically and then, more or less arbitrarily, to combine the horizontal and vertical figures in some relation to the latitude of the place in which the building might be raised. Presumably during the Summer in the Northern Hemisphere, the northermost line on the Earth at which the Sun appears to be perpendicularly overhead at midday travels from the Equator to the Tropic of Cancer and back to the Equator. The average summer line would therefore be halfway between the Equator and the Tropic. As the latitude of the Tropic of Cancer is about 23½ degrees, this average Summer line is located at about latitude 12 degrees. For average Summer conditions we could compare the Latitude of places to this line.

14. Thus if the latitude of the place of comparison were 22 degrees, we could take VSAH and HSAH of our figures and add together 5½ times VSAH and $1 \times$ HSAH, 5½/1 being approximately the co-tangent of the angle between the latitude 22 degrees and 12

degrees, viz., the co-tangent of 10 degrees. Thus comparing the shapes of paragraph 10 for buildings in Latitude 22 degrees North the comparison would be:—

(i) Square, sides facing compass points:
$5\frac{1}{2}$ VSAH + 1 HSAH = $5\frac{1}{2} \times 12a + 24a$ = 90a

(ii) Square, diagonals to compass points:
$5\frac{1}{2}$ VSAH + 1 HSAH = $5\frac{1}{2} \times 24a + 24a$ = 156a

(iii) Circle of area equal to above square, viz a^2
$5\frac{1}{2}$ VSAH + 1 HSAH = $5\frac{1}{2} \times 21{\cdot}26a + 1 \times 21{\cdot}26a = 158{\cdot}19a$

(iv) Long Rectangle, $2a \times \frac{1}{2}a$, long sides N. and S.
$5\frac{1}{2}$ VSAH + 1 HSAH = $5\frac{1}{2} \times 6a + 1 \times 30a$ = 63a

(v) Long Rectangle, $2a \times \frac{1}{2}a$, long sides E. and W.
$5\frac{1}{2}$ VSAH + 1 HSAH = $5\frac{1}{2} \times 24a + 1 \times 30a$ = 162a

15. From this comparison it appears that in Latitude 22 degrees North the Long Rectangle with the long walls facing N. and S. exposes less area to the direct rays of the Sun for a given volume than any other shape compared; and the long Rectangle with its long walls facing E. and W. exposes the greatest area of wall for a given volume of figure to the direct rays of the Sun. The former is therefore the coolest and the latter the warmest shape. It happens also that what turns out from these calculations to be the coolest shape is also the shape that catches most breeze from the south or the north, as the case may be, so that it would appear that this long rectangle facing North (or South) is unquestionably the coolest shape. This particular shape of rectangle where the long side is four times the short side would hold its own against the square, its nearest competitor among the shapes considered up to Latitude 57 degrees, but north of this latitude the square would absorb the lesser quantity of heat. Much below latitude 57 degrees north however the quest for coolness would have given place to the quest for warmth.

16. The Rectangle with the long walls facing North and South comes out best for building shapes with flat roofs flush with the tops of the walls. It would be worth investigating the relative heat-absorbing properties of different shapes of roofs. To make a fair comparison we should have to compare roofs of equal covering capacity and equal volume. The different types of roof would therefore have different heights. If we took the area covered as $= a^2$, and the volume that would have to be heated as $= \frac{a^3}{6}$ then

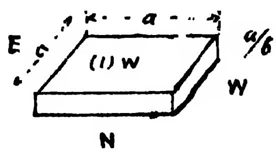
(i) For a Flat roof the height would be a/6.

(ii) For a pent or wedge-shaped roof it would be a/3.

(iii) For a pyramidal roof the height would be a/2.

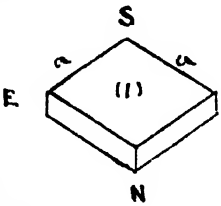
(iv) For a domed roof of which the dome is a hemisphere the height would be $\frac{3a}{8}$.

17. Compare these roofs by working out the HSAH and VSAH of each case and combining them, as for wall shapes. All the types may be considered to be covering squares of side = a. The first may be considered alternatively with the sides and corners to the points of the compass, the second may be considered with the gables either N & S or E & W. The sides of the square base in the remaining two cases face the points of the compass. In the fourth case the dome springs from inside the square leaving four corners to be covered by flat roof. The calculations are :—

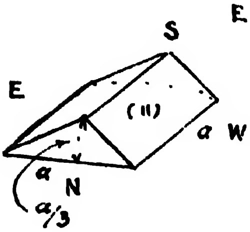


For (i) HSAH $= 24a \times a/6 \qquad = 4a^2$

VSAH (four square) = $12a \times a/6 + 12a^2 \qquad = 14a^2$

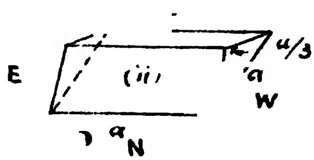


VSAH (corners to points) $= 24a \times a/6 \qquad = 16a^2$



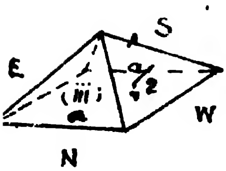
(ii) HSAH (if gables N & S) $= 2a^2 (1 + \sqrt{13}) \qquad = 9.2a^2$

HSAH (if gables E & W) $= 2a^2 (1 + \sqrt{13}) \qquad = 9.2a^2$



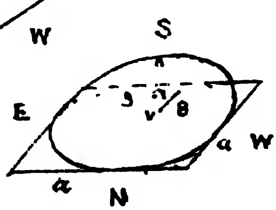
VSAH (if gables N & S) $= 10.8a^2$

(if gables E & W) $= 16.4a^2$



(iii) HSAH $= 24a \times a\sqrt{2} \times \frac{1}{2} = 8.5a^2$

VSAH $= 10.5\sqrt{2}\,a^2 \qquad = 14.8a^2$



(iv) HSAH $\qquad = 7.7a^2$

VSAH * $\qquad = 135a^2$

* For detailed calculations see Appendix I.

18. In Latitude 22 degrees North the comparison of these roofs would be as follows :—

(i) Flat roof, four square,
$5\frac{1}{2}$ VSAH + 1 HSAH = $(77 + 4)\ a^2$ $= 81a^2$

Flat roof, corners to compass points
$5\frac{1}{2}$ VSAH + 1 HSAH = $(88 + 4)\ a^2$ $= 92a^2$

(ii) Pent roof, Gables N. & S.
$5\frac{1}{2}$ VSAH + 1 HSAH = $(59.4 + 9.2)\ a^2$ $= 65.6a^2$

Pent roof, Gables E. & W.
$5\frac{1}{2}$ VSAH+1 HSAH = $(90.2+9.2)\ a^2$ $= 99.4a^2$

(iii) Pyramidal Roof
$5\frac{1}{2}$ VSAH + 1 HSAH = $(81.5 + 8.5)a^2$ $= 89.9a^2$

(iv) Domed roof
$5\frac{1}{2}$ VSAH + 1 HSAH = $(74.3 + 7.7)\ a^2$ $= 82.0a^2$

19. The comparison shows that for a given area and volume of roof, other things being equal, the pent roof with the gable ends north and south is the coolest form of roof and the same roof turned through a right angle is the warmest. The figures for the pent roof are for one with side slopes of three to two. The flatter the slopes the more nearly will the pent roof approach in heating capacity to the flat roof. The pent roof of the example will hold its own against the flat roof for heat resistance, or rather, smallness of exposure to heat absorption, up to latitude 42 degrees north, before reaching which the property of heat absorption would be more favoured. The domed roof compares favourably with other roofs and has much to recommend it.

20. A point that appears to arise from the above is that the usual method of roofing workshops appears to be the least favourable as regards heat conditions for India. The saw tooth roof is greatly used with long slopes on the south side and north lights nearly or quite vertical. These would appear to be essentially very hot roofs and it would be worth while carrying out temperature tests in exactly similar sheds with pent roofs differently disposed. If it turned out that the figures of para. 18 approximated to the truth, saw tooth roofs should have their gable ends north and south and lighting should be carried out through the gables or by skylights.

21. In this paper the periods during which the sun shines directly on a wall or roof have been considered, no account has been taken of the portions in shadow. Walls in shadow will absorb or give off heat according as they are cooler or hotter than the surrounding air. The quantities of heat so absorbed may be considered by comparison to be negligible, but the heat given off by a hot

wall in shadow might be very considerable. If so, obviously it is of advantage to increase the shadows. This can be done by providing cornices, chhajas and verandahs which cast shadows downwards, and by pillars, pilasters and buttresses which cast shadows sideways. The higher the latitude the wider should be the cornice, chhaja or verandah, which are but developments of the same idea, and the more numerous should be the vertical excrescences. The wide chhaja of Delhi, Agra, Gwalior or Jeypore is the result of the striving for more shade or shadow in the higher latitudes.

22. So much for walls. On the roof, shadows can be cast, especially in the more northern latitudes, by parapets running east and west, several to a roof; or the southern parapet could be made especially high to cast a very wide shadow. Another use could be made of this very high southern parapet as suggested in para. 28. The inner parapets could be made very thin and surmounted by little perforated pent roofs of their own to increase the shadow. These suggestions rather remind one of the efforts made to keep roofs cool by covering them with inverted gharas which after all do what they do by casting shadows.

23. It might be objected that all these excrescences are but added area and added mass for the absorption of heat, but it should be remembered that the usual building materials are not very good conductors of heat, and these things can be arranged semi-detached, perforated and ventilated and they can be made thin so as to cool rapidly when they come into shadow. Chhajas particularly should be perforated so as to ventilate and cool rapidly, otherwise each chhaja might be liable to hold a pocket of hot air against the outer wall instead of allowing, if not creating, an up-draft past the wall.

24. For small and low buildings shadows can be obtained from trees judiciously placed. Tall trees are advisable and such as shed their leaves in the cold weather so that when warmth is desired it might be obtained. The writer's practice for Railway Clerks' and menials' types of quarters was to place the quarters with the courtyards to the south and on the south of these to plant, ten or fifteen feet from the outer wall, either one Shisham or one Eucalyptus tree per unit of Clerks' or per 2 units of menials' quarters. It is a mistake to have too many trees with low branches as they retard cooling down at night.

25. Because of the rather comprehensive title of this paper something must be said about other matters of common knowledge that affect the coolness of a building. These are the reflective or absorptive properties of materials and their heat conducting and heat resisting powers. It is well known that all materials do not

absorb heat equally. Steel heats more readily than stone, stone than brick, brick than clay. Bright steel in the sun's rays will heat more slowly than dull steel and polished marble more slowly than unpolished. Certain colours are warm such as reds and browns, others such as blues and greens are cool. Dark shades of the same colours absorb heat more quickly than lighter shades. A case occurred in Unao many years ago where the day temperature of a house was lowered 13 degrees by white-washing the tiled roof.

26. If we are building for coolness we should remember these things and allow for them. We should make the South wall of any building in Northern India smooth and light coloured, give it extra mass or make it hollow. We should use for it smooth or polished, rather than rough, stone and brick rather than stone, we should plaster rather than point it unless its surface was prepared for reflecting heat. For our roofs we should use asbestos cement rather than galvanised iron, tiles rather than slates, jack arches, or even reinforced brickwork, rather than stone slabs and lime concrete rather than cement concrete of equal thickness. We should avoid dark materials, aiming in every way at a maximum of reflection and a minimum of absorption.

27. The use of hollow walls is often advocated and sometimes used, but it is questionable whether the usual slow cooling down of hollow walls does not make the average conditions of such walls no better than those of solid walls. Some years ago a patent was taken out for electrically pumping air through hollow walls. This might be an improvement but not everybody could afford the plant, possibly, and certainly current is not to be had everywhere that a house is built. But there is no reason why the Sun, which is everywhere, and which heats the building, should not take a hand in cooling it, as follows :—

28. Make the outer walls of the house hollow, but do not leave the hollowness in disconnected pockets. Make it continuous throughout the building, except that the north wall need not be hollow. The hollowness of the wall should be nearer the outside than the inside. Thus in a wall 1½ bricks thick the wall could be set out as though two bricks thick and an air space left between the outer half brick and the inner whole brick. There should be a reasonable amount of bonding to ensure the stability of the walls. Where the East and West walls were made 1½ bricks thick the South wall might be made 2 bricks thick, in which case the hollow would be in the middle. The South wall would be carried up to a high parapet which parapet would be hollow as a whole or in part. The function of the high hollow parapet would be to absorb the sun's rays rapidly to heat the air it contained, so that the air would expand and rise. With suitably arranged apertures near the top

the hot air would escape and if there were air inlets suitably placed a steady flow of air in the hollow walls would be set up. The position for the inlet vents would be low down on the North or cool face and they could be so arranged as to be sheltered, by carrying the East and West walls forward to end in pilasters on the North face and by placing the vents in the angles so formed, or in the relatively cool North verandah and in the vicinity of foliage plants or palms. These vents and possibly the outlets in the Southern High parapet would have to be provided with shutters as it would be undesirable to allow the pumping of air to go on during the cold weather months.

29. Normally, walls of buildings are made 1½ to 2 bricks, say 9 inches to 20 inches, thick, but roofs are seldom more than 10 inches thick in the thinnest parts and often they are less; in the cases of tiled, slated, shingled, and corrugated roofs, very much less. But roofs are shone on as much as South walls and they should be as thick. It is scarcely practicable to make all roofs 15 to 20 inches thick, but much the same effect can be obtained by the judicious use of ceilings. Imagine a thin flat roof of a house with the Sun shining on it all day. It gets very hot and the air on the underside in contact with it also gets very hot. By convection this hot air will stay at the top of room and if it is not disturbed the heat from this zone of heated air will reach the remainder of the room only very slowly by diffusion and conduction. But agitate the air and the heating process will go on rapidly and the temperature of the air of the whole room will be very quickly and considerably raised. Confine this hot air by a thin non-conducting ceiling, made of cloth for the poorer houses, of papier mâché, asbestos-cement or match-boarding for the better houses, and the heat absorption of the house will be greatly reduced. The space between the ceiling and the roof should be the maximum that can be conveniently given and there should be no connection between the air in the room and the air above the ceiling. In damp parts of India the ceiled space would require to be ventilated to check the sweating of the roof that otherwise would take place. In dry parts, as in the U. P. and the Punjab, ventilation might perhaps be provided, but it should be capable of being stopped, to make use of the ceiling against the rapid cooling of the room from the chilling of the roof at night in the cold weather.

30. Throughout the preparation of this paper the writer has in mind the heat of Northern India. To people who have not experienced this heat it is not imaginable. Certainly conditions in Calcutta and, as far as I can see, in the whole of Bengal and Assam are as different as they can be from those in the U. P. and the

Punjab. In these and other dry parts, where humidity is only experienced in the rains and the temperature of articles left in the Sun rises probably as high, in some parts, as 180 degrees, the doors and windows of houses are closed at about 9 a.m. and are not opened again before 5 p.m., and, it may be, not till a great deal later. People seal themselves into their houses and if they let air into the houses at all it is through khas tatties. Exposed Macadam and masonry become piping hot and do not cool till late in the night and sometimes not during the whole course of the night. Conditions can be greatly ameliorated if one has the use of large quantities of water, not only by means of the khas tatties, but, when evening sets in, by watering all adjacent macadam and masonry surfaces in the open air, watering the roof of one's house and the floors of the verandahs, also lawns and plants favourably placed. Not everybody knows of this use of water and not everybody can get the necessary water. Where water is available sprinklers on the roofs of houses would help matters very considerably, because turned on near sunset they would speed up the cooling down of the houses so fitted and would let them begin each day at a lower temperature than they would otherwise attain to. Besides, the moisture given off, if there were sufficient of it, as there might be if large numbers of houses were fitted, might locally tone down the Sun's rays, as presumably the moisture in the air does in Bengal and Assam.

31. The need for sealing up the houses in the day is unfortunate. In private houses the results are not bad because there is usually an ample reserve of air for the small number of persons occupying them, but in clubs and offices and places where people work, the need for fresh air is felt, and eithe khas tatties are used or hot air is let in through some of the doors or windows. The use of khas tatties is not always fortunate for they sometimes bring on colds and rheumatism, though people who use them wisely can usually avoid these troubles. Khas tatties as used are not altogether scientific. In themselves they are quite successful in the production of cooled air, but they are wrongly placed in the doors and windows on the floor it is desired to cool. The cool heavy air from them descends and there is no reason why it should rise again until heated above the temperature of the air immediately above.

Thus the feet of people are cooled rather than their heads. The proper place for the khas tatties would be about the level of the clerestories or actually on the floor above. The wonder is that this had not been thought of when everybody who can read knows that cool air descends. The coolness of the Tykhanas in Lucknow, in the Residency and La Martiniere (Constantia) for instance, must have been noticed by hundreds of persons. Yet as far as the writer

could see when he began his experiments it had not occurred to anybody to locate khas tatties at a high level, until one day, sometime after he had made his first experiments, the writer in the course of his duties climbed on the roof of a house built many many years before and found it fitted with special lofty skylights which were evidently used not so much for light as for ventilation, and not for taking out air but for supplying it cooled by khas tatties. The air shafts had apparently not been used for years for supplying cooled air and had degenerated into air extractors rather than suppliers.

32. But the writer had been arguing along similar lines to the builder of that house and was pleased to see this earlier effort, though rather different from his own, which aimed at the elimination of the moisture of the khas tatties, for two reasons, firstly, because of the reputed unhealthiness of the cold damp air and secondly because the cooling effects of dry air were so much greater than those of damp. The writer believed that a temperature of 92° of dry heat was much more desirable than a temperature of of 82° of moist heat. Force of circumstances brought the experiments to an end, but an outline of the principles along which the trials were proceeding and a description of the last stage of the apparatus tried might not be out of place. The principles are very simple, viz: Hot air rises, cold air falls. A hot chimney causes an updraft, a cold chimney a downdraught. Metals readily take up heat and readily part with heat. It takes a great many thermal units to heat water, it takes very few to heat air. Evaporation cools both the air into which the moisture evaporates and the surface from which evaporation takes place. The apparatus consists of a metal pipe surrounded by a water jacket. The cool water of the water jacket cools the pipe. The air in the pipe is cooled by contact with the metal. This air falls. If the top end of the air pipe is connected with an air inlet a downdropping stream of cooled air will result. But from the heat given up by the incoming air the water jacket will become warmed and means were required to keep it cool. The means provided was in the exhaust which was made to pass through porous pipes standing in the water jacket, thus recooling the water. The exhaust was forced by being connected with a heated chimney, heated by being exposed, above the roof, to the Sun's rays.

33. A more detailed description of the apparatus is given in Appendix II. The apparatus can fail by the inlet air coming in too fast. This can be controlled by throttling. The porous pipe might fail by being too porous and thus dripping, or it might become clogged. The first is a matter for experiment, the second a matter of convenience of renewal. In Appendix III the application of the

apparatus to the cooling of Railway carriages is discussed. The apparatus lends itself to the use of ice for cooling the water in the tanks and the cooler the initial temperature the cooler the average temperature of the incoming air could be maintained. The inlet of cool air would be placed at as high a level as possible and certainly above the level of ceiling fans. There is no limit to the number of inlets that might be used. The inlets would best be in the North verandah or on the North side in a partially open room. If the house were two storied it might prove best to have a northerly upper room cooled and to lead air by ducts from it.

34. No mention is made of power cooled rooms or houses These are not within the reach of all and the purpose of this paper has been rather to speak of things that could be provided as regular parts of the houses and which would not cost very much to main tain. The writer hopes that if there is any good in his suggestions they will be taken up and experimented with and that they might ultimately turn out to the general good.

35. In appendix III will be found an adaptation of the experimental cool air inlet to Railway Carriages.

APPENDIX I.

Calculations of vertical and Horizontal Sun Light Area Hours for different roof shapes. For diagrams see page 30.

(i) Parallelopipedal roof four square to compass points Square base of side = a, height = a/6.

$$\text{HSAH} = 6\left(a \times \frac{a}{6}\right) + 12\left(a \times \frac{a}{6}\right) + 6\left(a \times \frac{a}{6}\right)$$

$$= a^2 + 2a^2 + a^2 = 4\,a^2.$$

$$\text{VSAH} = (6 \times a \times a/6) + 12a^2 + 6 \times a \times a/6 = 14\,a^2.$$

Parallelopipedal roof, corners to compass points

Square base of side = a height = a/6.

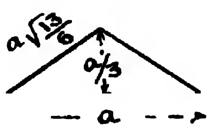
$$\text{HSAH} = (3a \times a/6) + (9a \times a/6) + (9a \times a/6) + (3a \times a/6)$$

$$= 24a \times \frac{a}{6} = 4a^2$$

$$\text{VSAH} = (2 \times 6a \times a/6) + 12a^2 + (2 \times 6a \times a/6) = 2a^2 + 12a^2 + 2a^2 = 16a^2.$$

(ii) *Wedge or Pent roof*, gables North & South

Square base of side = a. Height = a/3.



Length of one slope of roof $= \sqrt{\left(\frac{a}{2}\right)^2 + (a/3)^2}.$

$$= \sqrt{\frac{a^2}{4} + \frac{a^2}{9}} = \frac{a\sqrt{13}}{6}$$

$$\text{HSAH} = 6\,(a\sqrt{13}/6 \times a) + (12 \times \tfrac{1}{2} \times a/3 \times a) + 6\,(a\sqrt{13}/6 \times a)$$

$$= a^2\sqrt{13} + 2a^2 + a^2\sqrt{13} = 2a^2\,(1 + \sqrt{13}) = 2a^2 \times 4.61 = 9.2a^2$$

$$\text{VSAH} = 2 \times \frac{146^\circ}{180^\circ} \times 12 \times a\sqrt{13}/6 \times a = \frac{146}{45} \times \sqrt{13}\;a^2 = 11.7a^2$$

***Wedge or Pent roof*, gables East & West—**

Square base = a, height = a/3.

$$\text{HSAH} = 2 \times 6 \times a/3 \times a/2 + 12 \times a^2\sqrt{13}/6 = 2a^2 + 2a^2\sqrt{13} = 9.2a^2$$

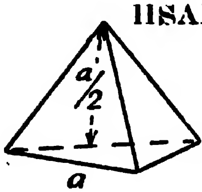
$$\text{VSAH} = 2 \times 6 \times a/2 \times a/3 + 12 \times 2 \times a\sqrt{13}/6 \times a$$

$$= 2a^2 + 4a^2\sqrt{13} = 2a^2\,(1 + 2\sqrt{13}) = (2 + 4 \times 3.61)\,a^2 = 16.4\,a^2$$

(iii) *Pyramidal roof—*

Square base of side $- a$. height $- a/2$.

$HSAH = 6 \times \frac{1}{2} \times a \times a/\sqrt{2} + (12 \times a/2 \times a/\sqrt{2})\ 6 \times a/2 \times a/\sqrt{2}$



$= 12/\sqrt{2} \times a^2 = 6\sqrt{2}\ a^2 = 8.5\ a^2$.

$VSAH = (12 \times 2 \times \frac{aa}{2} \times a/\sqrt{2}) + (9 \times 2 \times a/2 \times 9/\sqrt{2})$

$a/\sqrt{2}$ $a/2$

$= 21\ a^2/\sqrt{2} = 10.5\sqrt{2}\ a^2 = 14.8\ a^2$

$a/2$

(iv) *Hemispherical Roof*, diam. $= a$.

Square base of side $= a$, height $3a/8$.

The dome is a segment of a sphere.

Volume of segment $= \frac{\pi h^2}{6}(3d - 2h)$

Take $d = a$, $h = 3a/8$. Then Vol. $= \frac{\pi \times 9a^2}{64 \times 6}(3a - \frac{6a}{8})$

$= \frac{3 \times 3.1416a^2}{128} \times \frac{18a}{8} = \frac{84.8\ a^3}{512} =$ approx. $\frac{a^3}{6}$

Diam. of sphere of which this dome is a segment.

$$= \frac{\frac{a^2}{4}}{\frac{3a}{8}} \times \frac{3a}{8} = \frac{a^2}{4} \times \frac{8}{3a} + \frac{3a}{8} = \frac{16a + 9a}{24} = \frac{25\ a}{24}$$

$\therefore$ Area of dome $= \frac{3}{8} \times \pi \times \frac{(25a)^2}{24^2}$

$= \frac{3\pi}{8} \times \frac{625a^2}{576} = \frac{13\pi a^2}{32}$ approx. $= 1.28a^2$.

$HSAH = \frac{12}{2} \times 1.28a^2 = 7.68\ a^2$

$VSAH = 9 \times 1.28a^2 + 9\ (1 - \frac{\pi}{4})\ a^2 = 9 \times 1.28a^2 + 9 \times .22a^2$.

$= 9 \times 1.5a^2 = 13.5a^2$.

APPENDIX II.

Calculations and descriptions of Cool air Inlet for Houses.

1. In April 1916 I made certain observations of the cooling effects of evaporation off the surface of porous earthenware, as follows:—

The maximum air temperature during the period of observation was 101°. The air was as dry as it usually is in April in Lucknow the place in which the observations were made.

Water at a temperature of 91° was put into a matka at 11-10 Hrs. one day. It went through the heat of the day and the temperature at 17-30 Hrs. was 77°. The next day the temperature was 71 and on the third morning at 8 o'clock when the air temperature was 84° the water in the matka reached its minimum temperature of 69½°.

2. The range of temperature that concerns us and the apparatus sketched is that, say between 77° and 91°. With dry air and electric fans or punkhas the higher is a tolerable and the lower a cool temperature. We need not trouble about the lower temperatures of the second and third days.

Treating the matka as a sphere, the diameter being 13″ we get

$$\text{Volume} = \frac{\pi\, d^3}{6} \quad \text{where dia} = 13''$$

$$= \frac{22}{7} \times \frac{13}{12} \times \frac{13}{12} \times \frac{13}{12} \div 6 \text{ cubic feet}$$

$$= \frac{11 \times 13^3}{21 \times 12^3} = \frac{11 \times 2197}{21 \times 1728} = 2/3 \text{ cubic feet}$$

$$\text{Surface} = \pi\, d^2 \text{ where dia.} = 13''$$

$$= \frac{22}{7} \times \frac{13}{12} \times \frac{13}{12} = \frac{22 \times 169}{7 \times 144}$$

$$= 3.7 \text{ square feet.}$$

3. But the whole of the water in the matka is not in contact with porous surface. Assume that only 7/8 of the surface is available for cooling purposes, then

2/3 cubic foot water is cooled 14° in 6 1/3 Hrs. by a surface of $7/8 \times 3.7$ square ft.

1 c. ft. water is cooled 1° in 1 Hr. by $7/8 \times 3.7 \times \frac{2}{3} \times \frac{1}{14} \times \frac{19}{3} =$ 2.2 square feet.

Water requires 62.5 BThUs to raise 1 c. ft. 1° in temperature in 1 hr.

1 sq. ft. porous pipe absorbs $\frac{62.5}{2.2}$ BThUs per hr.

=28.4 BThUs per hr.

4. At the time that the above mentioned observations were made, i.e., with a maximum air temperature of 101° it was observed that a room on the N. E. corner of a house rose in temperature, the room being closed to exclude warm air from outside, from 84° at 9 a.m. to a maximum of about 92°—this maximum being reached at about 14 Hrs. It may be taken that this room warmed up 8° in 5 Hrs. It is admitted that the observations were insufficient to establish all that it might be desirable to establish, but they gave some information to begin work on. Because the room was on the N. E. its walls ceased to be subjected to the direct rays of the Sun at 12 noon. Only the roof was shone upon after that hour. The chances are that there was little actual increase in the temperature of the room after 12 noon. Assume that this is so and that the rise of temperature from 84° to 92° took place in 3 Hrs.

1 BThU will warm up 55 c. ft. of air 1° in temperature.

The size of the room was 16′ × 17′ × 18′. The number of BThUs that it would absorb to raise the temperature 8° would be

$$\frac{16 \times 17 \times 18 \times 8}{55} = \frac{39168}{55} = 712 \text{ BThUs.}$$

Add some 25% to this to allow for errors and hotter days, then we may reckon the number of BThUs per hour absorbed by the room as 300 BThUs.

5. A healthy adult gives off some 15.6 c. ft. of air per hour when at rest and more than double this when working hard. Suppose he gives off 25 c. ft. at a temperature of 98.4°. Suppose it is desired to reduce this temperature to 84° then the number of BThUs per hour to be absorbed = $\frac{25 \times 14.5}{55}$ BThUs per Hr. =6.6 BThUs per hour which is negligible compared with the 300 BThUs above. Even allowing for three or four persons in so small a room the percentage of increase of BThUs would not be more than the percentage that may be allowed in the making of the apparatus for just such contingencies and variations of manufacture.

6. Now it is desired to ventilate a room 16′×17′×18′ absorbing 300 BThUs per hour from the Sun and maintain the temperature of the room at the same temperature as it begins in the morning, say in this case, 84°.

The air will be taken from the North, or cool side. Suppose the temperature of the outside air on this side is 120°. The temperature of the air let into the room must be somewhat lower than 84° in order that 300 B Th Us of heat might be absorbed by it and the temperature not raised above 84°.

Suppose that the air cannot be cooled before entry below a temperature of 80°. Then the quantity of air at this temperature that must be provided per hour to absorb these 300 BThUs is

$$\frac{300 \times 55}{4} \text{ c. ft.} = 4125 \text{ c. ft.}$$

$$4125 \text{ c. ft. at } 80° \text{ is at } 120° = 4125 \times \frac{(491+40)}{491} \text{ c. ft.}$$

$$\frac{4125 \times 531}{491} = \text{say } 4500 \text{ c. ft.}$$

7. The air supply is 120° in temperature. This must be cooled to 80°. Therefore the cooling apparatus must be capable of absorbing

$$\frac{4500 \times 40}{55} \text{ BThUs.} = \text{say } 3300 \text{ BThUs.}$$

Observation showed that porous pipes are capable of lowering the temperature of water to 69°. If the water in the cooler began at this temperature at 8 a.m. it should not rise in temperature above 78° by 12 o'clock and the quantity of water that in four hours would absorb 3300 BThUs for a rise in temperature of 9°

$$= \frac{4 \times 3300}{9 \times 62\frac{1}{4}} = 23\tfrac{1}{2} \text{ c. ft.}$$

But evaporation off the surface of a porous pipe would be capable of lowering the temperature 9° in 4 hours, so it is not necessary to provide for more than one hour's supply of cooling water and the size of the tank need not be greater than $\frac{1}{4}$ of the above, or say of 6 c. ft. capacity.

8. If we made this 6 c. ft. tank 3 feet deep its area would be 2 sq. ft.

The area of exposed porous surface required to cool 6 c. ft. water in contact with it $2\frac{1}{2}$° per hour (conditions only require $2\frac{1}{4}$)

$$= 5\tfrac{1}{2} \times 6 = 33 \text{ sq. ft.}$$

Pipes 3 feet long with a total surface of 33 sq. ft. would require a total width of 33/3 = 11 ft.

Make the pipes $5\frac{1}{2}''$ internal diameter then the number of pipes $3' \times 5\frac{1}{2}''$ required to cool a 6 c. ft. tank of water $2\frac{1}{2}$° per hour =

$$11 \times 12 \times 22/7 \times 2/11 = 8 \text{ about.}$$

The area that 8 pipes 3 feet long will occupy in the tank of two foot area $= 8 \times \frac{22}{7} \times \frac{11 \times 11}{2 \times 2 \times 4} \times \frac{1}{144}$
$= 1.32$ sq. ft. (plus an allowance for thickness).

9. To find the size to make the opening for the inlet of fresh cooled air :—

Temperature of air in cooler	$= 80°$
Temperature of air in Room	$= 84°$
Depth of cooler	$= 3'$
Height of column of descending air	$= 3'$

Co-efficient of expansion of air $= 1/491$ per degree.

The column of air at 84° required to support a 3′ column at $80° = 3$ plus $\frac{4}{491} \times 3 = 3\ 1/41$.

The cold air will descend with the velocity of a body falling through 1/41 feet.

$V = \sqrt{2gh} \quad = \sqrt{2 \times 32.2 \times 1/41} = 1\frac{1}{4}$ feet per second.

The air required is 4500 c. ft. per hour. Therefore size of inlet required $= \frac{4500}{60 \times 60} \times \frac{4}{5} = 1$ sq. foot.

10. The quantity of air coming into the room is 4500 c. ft. per hour. The quantity of air going out should be the same. This will pass through porous pipes, the cross sectional area of which is 1.32 sq. ft. The velocity at which this air would pass through the porous pipes would be $\frac{4500}{1.32 \times 60 \times 60} = .95$ feet per second, which should be fast enough to evaporate moisture on the surface of the porous pipes.

11. The exhausting agency would be a black iron chimney 6 feet high exposed to the heat of the Sun. Suppose the chimney heats to a temperature of 140°. The temperature of the room from which air is to be exhausted is 84°. The difference of temperature is 56°.

Velocity of out-going air $= 8.2\sqrt{h}$ where $h =$

$(h = 6 + (56/491 \times 6) - 6' = .7)$. $\therefore = 8.2 \times \sqrt{.7}$ feet per sec.
$= 6.9$ feet per second.

4500 c. ft. of air per hour pass through this chimney. The cross sectional area of the chimney to pass this quantity of air should be

$$\frac{4500}{6.9 \times 60 \times 60} \text{ sq. ft.} = 26 \text{ sq. in.}$$

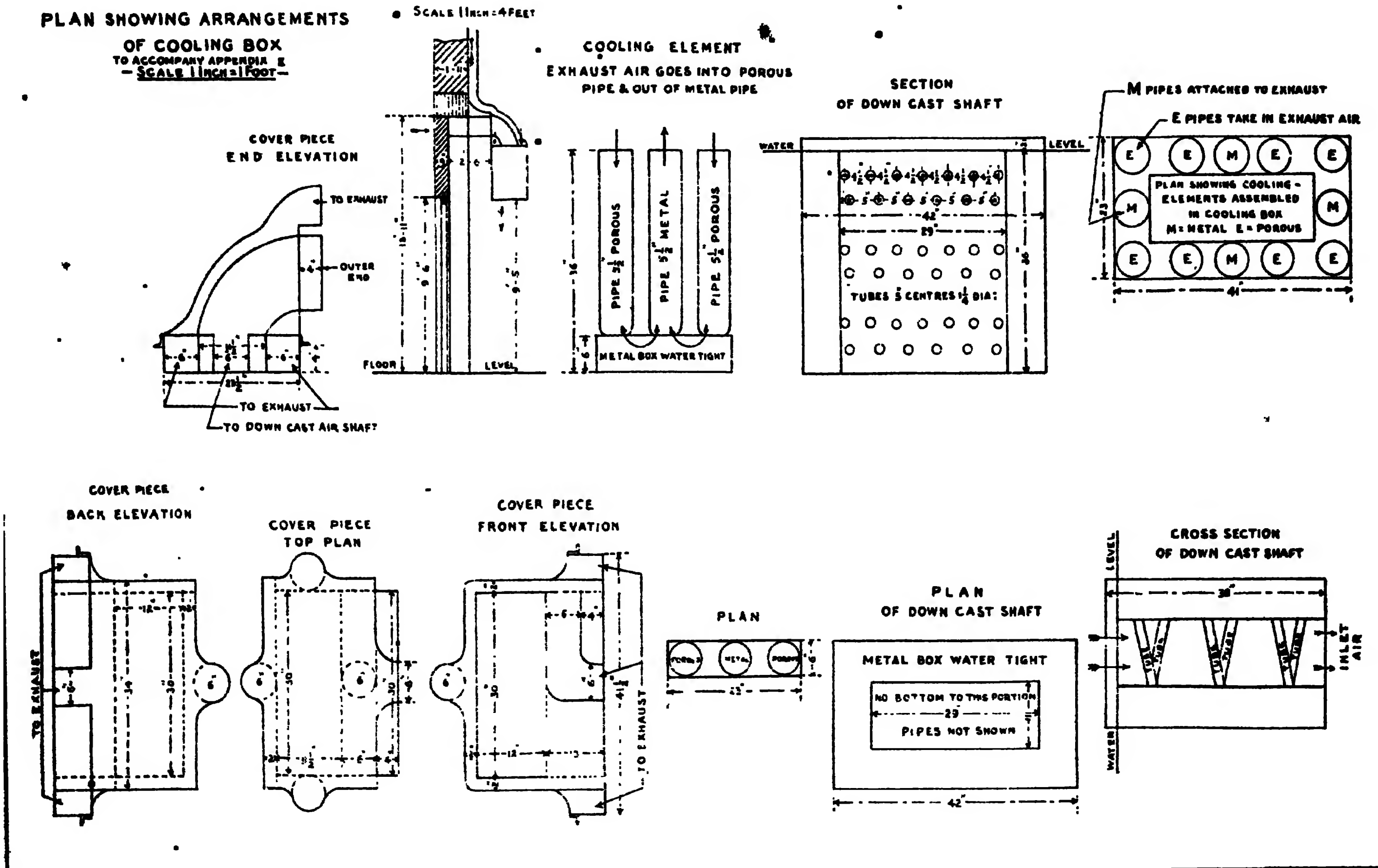
Add 20% to this for friction and the diameter of pipe necessary works out to $6\frac{1}{2}$ inches.

12. With the figures worked out in the preceding paragraphs we can proceed to design our apparatus, erring always on the liberal rather than on the close side in our dimensions. The drawing accompanying this appendix was prepared many years ago and it is now discovered does not quite fit the calculations. The design also is rather elaborate but any Engineer can prepare a simpler design fitting the calculations. It is clear, the writer believes, that the addition of a few seers of ice to the water container every morning would greatly improve the cool air supply. The water cooling units should be so designed as to be easily removed and replaced. They should as far as possible be all alike.

PLAN SHOWING ARRANGEMENTS OF COOLING BOX

TO ACCOMPANY APPENDIX E

— SCALE 1 INCH = 1 FOOT —



APPENDIX III.

1. Much of what has been said in the accompanying paper on Cooler Housing applies *a fortiori* to Railway carriages. The railway carriage is a box on wheels in which in India men, women and children often spend long periods of time. In some parts of India travel in them is not too bad, even in the hottest weather, so long as the train is moving or the air can be agitated. But in the drier and hotter parts the heat in a Railway train often beggars description. Where there are many persons in a compartment it is hard to do without opening the windows to let fresh air in and the temperature of this fresh air might be as high as 140° or more. With the windows closed and only one occupant per compartment the rising of the temperature to 140° is only retarded. In the upper class carriages, the action of the ceiling fans, which it is impossible to do without, merely speeds up the heating of the compartments, for they drive air downwards towards the floor from which it rises all round along the heated sides and close to the more heated ceiling or roof to descend again by the force of the fan. Moist cloths hung in the air-stream at a high level help to mitigate the hardship but the very moisture is inimical to prolonged improvement. A cool air inlet and a hot air exhaust is required in each small compartment and more in larger. The very motion of the train is helpful towards both pumping in cool air and exhausting the warm, and when the train is not in motion the ceiling fans can be made to help matters, more than one way would be suggested to anybody giving the matter thought. Exhaust air would probably always be taken out through the roof, inlet air might come in through the floor, the ends or the sides; in the case of the sides the user could be given the option of taking it from one side or the other in order that the sunny side might be avoided.

2. The following is a description of the combined cool air inlet and hot air outlet proposed as a unit for a railway carriage or compartment. If drawings were prepared of this they are not forthcoming, but the sketches will serve to indicate the nature of the apparatus.

3. Assuming that the maximum temperature mentioned above is somewhat exceptional, there is no doubt whatever that 120° is a common enough temperature in a Railway carriage. The apparatus is designed to the following data :—

Size of compartment	$10' \times 10' \times 8'$	
Temperature in the morning at 8	...	=82°, say
do. at 12 noon	...	=120°, say

The endeavour will be to keep it at 92°

The temperature increases 120°−82°=38° in 4 hours.

No. of B.Th.Us absorbed $= \frac{10 \times 10 \times 8 \times 38}{55 \times 4}$ per hour

=138 BThUs per hour.

138 BThUs per hour would raise in temperature 1°

138 × 55 c. ft. of air per hour.

=7590 c. ft. of air per hour, and if the opening through which this entered were made of a clear area of ¼ sq. ft. the velocity of the incoming air would be 8.4 feet per second or about 6 miles an hour, a reasonable speed.

Suppose the air outside has a temperature of 140° and this has to be lowered to 91°. Then the cooler must absorb

$\frac{7590 \times 49}{55}$ BThUs per hour

=6762 „ „

At night with the air playing through it the cooler will tend to cool down very considerably, and 75° should not be an unreasonable minimum temperature for the water to attain in a moving train. Taking the morning temperature of the water at 8 a.m. as 75° then the volume of water required in order that, absorbing 6762 BThUs per hour, the water, by 12 noon, should not rise in temperature above 91° $= \frac{6762}{15 \times 10} = 45$ gallons.

But a porous pipe can lower the temperature 15° in 4 hours and the tank need not contain more than 45/4=11¼ gallons.

The area of porous pipe that would be required to lower the temperature 150° in four hours would be

5½ × 15/10 sq. ft. per c. ft. of water=7½ sq. ft.

4. Porous pipe 5″ dia. has surface per foot-run of 1 1/3 sq. ft.

Area of porous pipe required to cool 11¼ galls.

$= \frac{45 \times 4}{4 \times 25} \times 7\frac{1}{2} = 13\frac{1}{2}$ sq. ft.

Therefore length of pipe required=10 feet.

The box should be at least half this length. Make it 6 feet long inside.

Inlet occupies 1/4 × 6 c. ft. =1½ c. ft.

Outlet occupies $\frac{2 \times 22 \times 25 \times 6}{7 \times 4 \times 144}$ =1 5/8 c. ft.

Total capacity of box to be water 1⁴/₅, inlet 1½, outlet 1⁵/₈

=say 5 cubic feet.

Length of box=6 feet. Width must equal 1″+6″+10″+1″

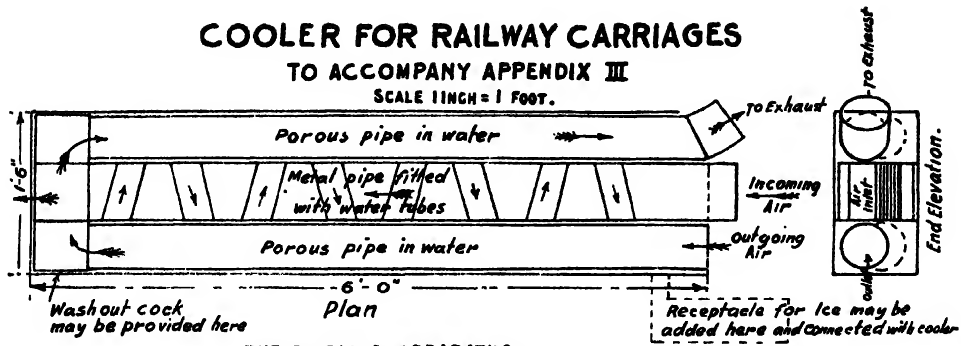
=18″

Then depth=5′ × 1/6 × 2/3=say 7 inches.

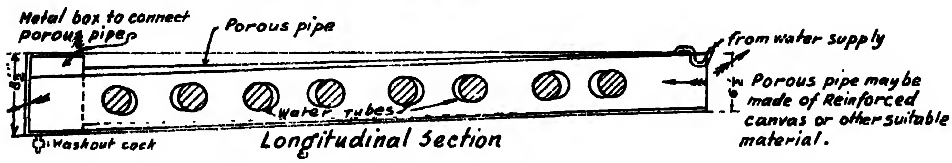
COOLER FOR RAILWAY CARRIAGES

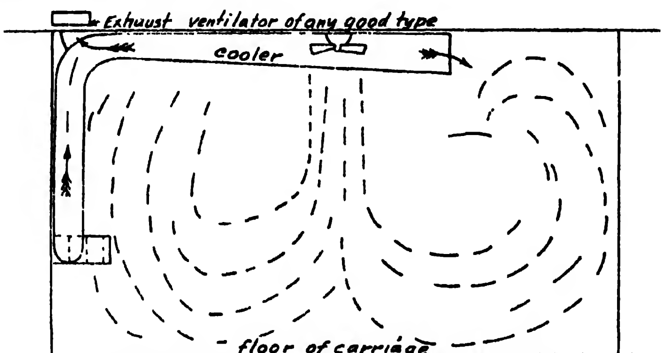
TO ACCOMPANY APPENDIX III

SCALE 1 INCH = 1 FOOT.



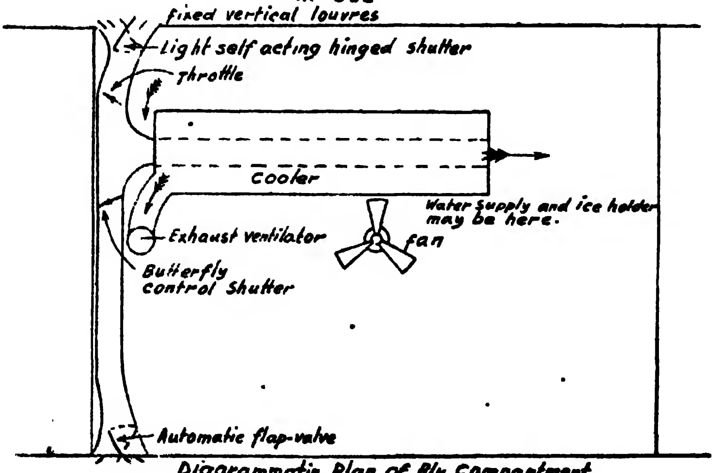
THE COOLING APPARATUS





Diagrammatic Longl Section of a Rly Carriage

THE COOLER IN USE



Diagrammatic Plan of Rly Compartment.

DISCUSSION ON COOLER HOUSING.

CORRESPONDENCE.

Mr. J. W. Meares remarked that he was interested in Mr. Morgan's paper, because he took out the patent referred to for the use of hollow walls combined with air-cooling by fan. The Delhi authorities got so far as to design two houses, identical in every other respect, one with solid walls and the other on his principle; but the war stopped their construction, and he did not keep up the patent. It was therefore open to anyone to construct such houses. The cost was some 20 per cent. higher but the running expenses were not serious where electricity was reasonably cheap. Mr. J. W. Meares.

It seemed, however, probable that some combination of Mr. Morgan's ideas and his own might be feasible and more economical. It was well known that solar heat had been used in Egypt for an experimental power plant, with the help of mirrors. If a hollow walled building was constructed, with sectionalized air passages in accordance with his design, and with similar thermantidote arrangements, direct solar heat, supplemented possibly by reflectors, could perhaps be utilized to give the necessary up draught to the air from a blackened drum, a short iron chimney being used as the final outlet.

In theory the principle would work. If it were successful in practice it would do much to alleviate the hot weather in dry localities—of course it would be useless in places like Bengal. It seemed surely worth while for Government to start where they left off in 1914, and to build one pair of comparable houses as a promising and inexpensive experiment.

Dewan Bahadur A. V. Ramalinga Aiyar said that the paper was an interesting one and no doubt provoked thought on a subject which had had very little attention bestowed to it. The subject, *viz.*, Cooler Housing was rather fascinating but was a very complicated one. There were ever so many factors that entered into it, and obviously only a very few of them had been dealt with in the paper; naturally what place these had, how far they affected, what was the contribution these made in cooler housing, were still in the region of experiment and elaborate experiments were required before these questions could be answered. Consequently, Dewan Bahadur A. V. Ramalinga Aiyar.

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considering the cost of building houses, the fact that however much an Engineer was anxious to conduct experiments on a scientific basis, in the absence of help from the State, his progress would be limited by his purse and could not even for the richest of the Engineers extend to more than a house or two. The progress would be very slow unless Government or some rich Institution could take this up for special investigation.

Let it be seen for a moment what these other factors were:—nearness to hills, nearness to the sea, proximity to a wooded forest, proximity to lakes, elevation, direction of winds, general rainfall, wet months, dry months, cloudy months, humidity, etc.

Thus none thought of cooler housing either at Ootacamund or in Mercara, or in Bangalore. Cooler housing at Madras would be a somewhat different problem from what it was on the West Coast. In one place the Sea was on the East and in the other on the West. Similarly, places with hills on the East would have to be dealt with differently from those which had them on the West; places on one side of a wide river or a large lake would receive a different treatment from those on the other side. The author, himself, had recogised the difference in para. 29, between a humid and a dry place.

Out of a host of elements, the author had dealt with only one, *viz.*, the effect of sunshine. Here it must be said that it was not clear had he derived the coefficient as cotangent in para. 14. This would have to be explained further. Then again where factors such as shadow, etc., had not been elaborately dealt with, it might not be even conducive to any accuracy to leave out the factor mentioned in para. 12. It would be worth while investigating this mathematical theory a little further and assessing the effect of the angle of impact at different hours in the same day and in different months. We were of course concerned only with the hot months in each place.

Theoretical considerations, no doubt, led to north facing in the northern latitudes but this was unfortunately one of the impositions of the western engineering conditions and had now been given up even by the Government which constructed most of its 19th century buildings on that idea. The southern Indian on the East Coast always preferred a south facing building perhaps for the following among other reasons:—

(*a*) He got the south-west monsoon winds but not the rains and this monsoon coincided with this hot season.

Dewan Bahadur A. V. Ramalinga Aiyar

(*b*) The south facing rooms got plenty of light and at the same time were not exposed either to the morning or evening sunshine, the former being more unwelcome.

Again the Indian in cities was more confined to living in streets and here again the south facing of the individual houses meant the east facing of the entire block which accorded with the authors idea.

Earlier portions of the paper were no doubt very useful in that they explained the idea of sunlight houses but the paper rather abruptly turned to the subject of shadows without telling us how the theory had been applied, if it agreed with practice, etc. The same applied to the methods of cooling houses and railway carriages. He hoped that the author would be able to apply these methods and give us the benefit of his further experiments. From a comparison of the sunlight houses, it had been made out that a pent roof was cooler than a flat roof but this was with no allowance for the fact that the former was a much thinner roof and would therefore permit radiation and conduction on a larger scale.

No doubt from the angle that the author viewed the use of khas thatties, its position seemed wrong. Let it be considered in this way. There was the room with its air contents of which only the bottom 6′ or 8′ height were used. The upper portion contained hot air which could only go up and could not come down. Air was a fair nonconductor. And let us suppose that the room had sufficient doors and windows up to a height of 8′. Then obviously it was not worth our while to be cooling all the upper air above 8′ and it would suffice if we did it for the height we used, and so long as sufficient replacement of this air required for breathing purposes which the author had shown was comparatively a small quantity then there was no object in cooling the upper air and inducing a draft much above what was required for air purposes.

There was one other point he wished to mention and that was, that comfort in hot weather perhaps depended more on the absence of sweat than even on temperature and so long as a ceiling fan did this and also helped to cool the air in the bottom 8′, even its position as actually adopted might not have any serious drawback and even a ceiling fan could not in a large room induce more than a few ripples which would die in the room itself and so a ceiling fan did not induce any heavy draft.

Dr. K. C. Chakko.

Dr. Chakko said that gardens and trees had an important influence on the coolness of a dwelling house. The nature and direction of wind also affected the temperature. The author discussed

K. C. akko.

the problem mainly from the design of the house. There was a possibility of other aspects being considered of minor importance, or of no importance at all, whereas it was quite possible that gardens and trees suitably situated might give cooler houses more cheaply than by special design.

o Bahadur V. Krishna-amy etty.

RAO BAHADUR KRISHNASWAMI CHETTY remarked that while appreciating the work of the Author of the paper "Cooler Housing," he would like to point out that the Author could well have mentioned something about the use of Electric Refrigerating Apparatus for cooling houses. He anticipated that in the next few years there would be small, cheap and economical refrigerating blowers for domestic use. Such a unit would cost not more than Rs. 1,500/- while the current consumed by the Refrigerator would be about 5 units per day. This apparatus would be suitable for an average minimum sized building.

. E. E. sbruslais.

MR. E. E. DESBRUSLAIS said that the subject involved two general lines of investigation

(*a*) The existing heat

(*b*) The protection of the interior of houses from this heat.

The Author had attempted to give his reasonings a mathematical appearance, but there were many contradictory, illogical and incorrect statements which required explanation before, the subject as investigated by him, could hold with the accuracy of mathematical deductions.

First of all in regard to para 3, it was well known that the prevalent breezes, north of the tropic of Cancer and in places like Patna, blew in the hot weather from West to East coming from the Punjab deserts and were not North and South. It was for that reason that the engineers in that place, planned their buildings with the long axis running North and South. In para 32, the Author stated that "92° of dry heat was much more desirable than 82° of moist heat."

In regard to para 6 the Engineers of Patna took advantage of the cool North side for bed rooms etc. and did not add verandahs on that side, making the building much cheaper; and in the case of Educational buildings they placed the long axis East and West without a verandah on the North side, getting the advantage of the even light from that side, so essential, without the glare of the South light.

In para 5 the Author seemed to think that orientation was the most important part of the lay out of buildings, which would

Mr. E. E. Desbruslais.

render architectural forms impossible, and only box-like structures necessary, this practice was not at all universal and would be hideous. Coming to the mathematical part, it was evident from what he called in paras 7 and 10 HSAH, that any area parallel to the Horizontal was counted as not heated by a Horizontal moving sun; whereas when he came to what he named VSAH, he did not omit any areas parallel to the Vertical moving sun (a) the former excluded the roof area, and the latter which should include only the roof area, included the heating of the vertical sides. This was illogical; as the premises are changed in each part of a mathematical reasoning, for the same subject. As for example taking para (10) (iv & v) the vertical SAH would be 4 times as much in the former as in the latter case and if 12 hours was recorded as the maximum number for heat area in the former the VSAH for iv would be $12a^2$, for heat area in the latter the VSAH for v would be $3a^2$ and not $6a$ and $24a$ respectively.

For IV we got $\left.\begin{array}{r} \text{HSAH} = 30\,a \\ \text{VSAH} = 12\,a^2 \end{array}\right\}$ lay walls face N. & S.

and For V we got $\left.\begin{array}{r} \text{HSAH} = 30\,a \\ \text{VSAH} = 3\,a^2 \end{array}\right\}$ lay walls face E. & W.

and so the orientation of the latter would seem to be better than the former and the best which was not the conclusion arrived at by him in para 15 and 16.

In fact as the Sun was never at all horizontal when the heat from it, was effective, but on the contrary was nearly vertical when the heat was effective, it would appear that orientation, if above considered, would be guided by the VSAH . . for the roof and not by the HSAH of the walls; and the HSAH in both cases of IV and V were the same as calculated by the author.

From Para 16 to 19 the Author seemed to commit the error of combining the heating part with the part for protection against the heat and his conclusions were incorrect.

What he meant by a flat roof of height $\frac{a}{6}$ was no more than a thickness of $\frac{a}{6}$ which in case of a building say a = 36′ or 72′ long × 18 ft. wide (a Barrack) would require a roof $\frac{36}{6} = 6'$ thick, whereas a corrugated iron gable roof with a thin ceiling would protect the interior from heat quite effectively or a flat roof with a thin ceiling.

E. E. Dabrulais.

What did a roof, flat, 6′ thick for such a building resolve itself into when considered from a hollow point or from a workable economical point of view?

The Author did not give any result which would lead Engineers who studied his paper, to come to any conclusion. It was not the volume of roof to absorb the heat from the sun that was the most economical, but the spacing between roof and ceilings of a column of air always in circulation, as in the case of hollow walls recommended by the Author in paras 27 & 28.

The paras. relating to shadows in paras. 21 to 25 were very instructive and very useful and should be a guide in design.

In para. 26 the remark that the roofs should be of Asbestos Cement among other materials led him to mention the great progress made in this material which was known as " Italit."

The Asbestos Cement was supplied in flat sheets for ceilings and walls (leaving an air space for cooling); in the corrugated forms and flat tiles for roofs the colours being in Grey and Red. The coolness of a House utilizing these materials could well be imagined.

He had arranged to get a two storied house, hot upstairs on account of a very low roof and no verandahs, covered with this material using the existing pucca roof as a ceiling. The author's suggestions would guide him.

The note on Khus-Khus-tatties in paras. 31 and 32 gave scientific ideas for their use, and would be very useful to all who used these and the apparatus mentioned and designed by the author in paras. 32 and concluding paras if taken up commercially, would do away with the waste in the use of Khus-Khus-tatties in their renewal and maintenance. In large institutions their benefit would be untold. Was the formula on page 16, Area of Dome $= \frac{2}{3} \times \pi \times \left(\frac{25}{24} a\right)^2$ correct? Should it not be $\frac{3}{2} \pi \left(\frac{25}{24}\right) a^2$? The area of the surface of zone is $2\pi RW$.

From the calculations in the Appendix given by the author it appeared (with regard to roofs of different types) that the author had promised the following:—

"That with roofs of the same covering area and same volume presented to a Vertical Sun, they were heated differently owing to their presenting different excrescents to the beating vertical rays" the reason being that the Vertical Sun had to travel a longer distance over these than over a flat surface.

Mr. E. E. Desbrusiai

This was not true for if the position of the sun at any moment with reference to trilinear rectangular co-ordinates was considered it would be seen that firstly all three co-ordinates of the intensity of any ray oblique to the roof were less than the original. Secondly that two only out of three could affect the roof with any excrescent above the covering area, a horizontal and a vertical resolute. Thirdly the total intensity would be either of these multiplied by the projected area of the excrescent on planes normal to them, which was certainly not what the author assumed as premises for his calculations.

II. If for comparison we followed the author and allowed only a vertical ray perpendicular to the covering area of the roof, then the value of the intensity would be, the vertical intensity multiplied by the area of the horizontal covering area (a) would be same for all roofs; the time total intensity would depend, on the orientation of the building (or its roof) being small when the smaller axis of the building was East and West and larger when the longer axis was East and West. The results from this were contrary to the author's predictions as shown before.

III. Using trilinear co-ordinates (rectangular) for any position of the sun, we should further see that of the three co-ordinates, only that one which was horizontal and perpendicular to the sides (walls) of the building could be considered as able to heat them directly by impinging on them, the other two co-ordinates (a vertical and horizontal) lay in planes parallel to the walls and hence did not affect them the surrounding air would be heated only; these rays would not impinge on the walls. This had been dealt with in previous paragraphs, as different from the author, who had taken into account vertical rays when dealing with the walls of a building.

The Author

In reply remarked that he was wholly in agreement with Mr. Meares that the subject was worthy of experiment. He would not, however, use any plant at all for smaller houses, but would design them so that the heat of the Sun and a certain amount of manipulation would do all that was needed. For larger buildings, mechanically, electrically, or otherwise, forced draughts might be needed to supplement the design and might prove economical. Very large buildings alone could justify the use and cost of refrigerating chambers and the like.

To deal adequately with the subject of "Cooler Housing" would require a treatise, not a paper. Experiments could be carried out anywhere where numbers of buildings of the same type

Author. were being erected, whether by Government or by Private enterprise. Only comparatively unimportant differences need be made in the various structures for the purposes of experiment, but close watch would have to be kept over operation and close records of results.

He had dealt in his paper with certain principles; obviously locality affected one's outlook and should be given due weight. Humidity would not greatly affect the principles, but would certainly affect the methods of design and the results. It would be the duty and, one hoped, the pleasure, of every designer to consider every factor and allow for it. All the points mentioned in the criticism did not have any effect on the course of the Sun.

Mr. Aiyar accused him of having dealt with only one out of a whole host of elements, viz., the effect of sunshine. It was the sunshine that caused the heat, not only of the building itself but of the whole land we live in. The problem he had tried to deal with in part of his paper was how to place out buildings so that they would absorb the least amount of heat, which he had taken to mean how to place our buildings (each case should of course be treated individually) so that the least amount of surface would be exposed to the Sun's direct rays.

There was no difference from the point of view of the paper between Southern facing and Northern facing. See para. 6 where "the orientation of dwelling houses so that the major axis runs East and West" was referred to. Whether the North or the South was made the front of the house the Sun shone on the South side. Breezes could blow through such a house just as well through the back as through the front. The designer must give due weight to every factor and he must *know* his factors.

Mr. Aiyar complained that he had not said how the theory agreed with practice. He would refer him to the last sentence in the first para. of his paper. About the remark concerning the comparison of flat and pent roofs he must compare comparable things. Obviously where shapes were being considered the materials and other conditions must not be dissimilar.

What Mr. Aiyar said about khas tatties was right up to a point. But he did not want, and avoided, stagnant air in rooms, particularly in hot climates; the air was kept moving if it was possible. One way might be by having "sufficient doors and windows up to the height of 8 feet." Nobody would fit all these with khas tatties and if they did and could arrange a blow through them there would still be an inwardly descending slope of cooled air. The lowest layers

of air would be coldest, and with chilled feet and warm heads would come, he believed colds and rheumatism. Better a higher temperature of more uniformly cooled air with the cold air splashing into the room from a height like water into a cistern, setting up currents and eddies which in themselves, by definite movement would help carry away moisture from the skin. The Auth

The "absence of sweat" that Mr. Aiyar found as a desideratum was largely a matter of the moisture content of the air. Even if such air could be kept moving the nearer it was to saturation the less would it take up of moisture from the body however much it was agitated. The ceiling fan did not cool the air, it merely blew it down to find its way up again along the walls.

He would refer Dr. Chakko to his paragraph 24. Lawns and trees judiciously placed and the former regularly watered have considerable cooling effect, but trees could be overdone. The writer had had experience of places made warm by too many trees which were considerably improved both in coolness and appearance by judicious thinning out.

He would refer Rao Bahadur C. V. Krishnaswami Chetty, to his reply to Mr. Meares's remarks. Poorer people have not yet got to Punkhas and electric fans and he would improve the conditions of life for such people also, by the proper design of their houses and their surroundings. Mr. E. E. Desbruslais had done him the honour of studying his paper in great detail and commenting on it at length. He was not sure, however, that he had not given the mathematical side of it rather exaggerated importance. It would appear also that he had his facts wrong with regard to Patna.

He had nowhere suggested that orientation was the most important part of the layout of buildings. He had merely attempted to show that it was a factor which was at least worth consideration. Nor did his arguments render architectural forms impossible. There was no reason why a structure should be boxlike merely because its major axis should preferably lie one way rather than another. Where Mr. Desbruslais said he was illogical he had not his facts right. The comparisons made in paras. 7 and 10 dealt with walls only. Would not a Sun rising in the east and setting in the west and moving in the vertical plane between these points shine for half the day on the east wall and the remaining half on the west wall? In para 14 an effort was made to combine horizontal and vertical figures, the roof being ignored in every case because the roofs were all equal and the Sun shone on these roofs the same amount in each case, viz., all day long. It might be

Author. noticed also that the multiplier of VSAH was $5\frac{1}{2}$ whereas of HSAH it was only 1.

He was afraid his critic had misunderstood paras. 16 to 19. Roofs to be comparable must be considered to be of the same materials, not of various materials. For fair comparison all the roofs must have the same volume. Pent, pyramidal, conical and doomed roofs stood on definite bases and had definite volumes above these bases including the volumes of the materials of which they were made. Flat roofs made of the same materials would have considerably less volume. To give them equal volume they must be given a parallelopipedal form. Thus the horizontal surface of the flat roof of the comparison was raised a/6 above the walls and vertical pieces of "roofing" extend downward to the tops of the walls. There was no suggestion of making a flat roof 6 feet thick. Thickness was not referred to at all.

The volume of a dome as given by Mr. Desbruslais was correct, not as printed on page 16 of the paper.

In his comparisons not only the vertical rays of the Sun were considered but the whole period of the day in which the walls or roofs were shone upon. See para. 12. The angle of total absorption was assumed at 0°, not at 90°. Different materials had different angles of total absorption, some reference to which was made in para. 25.

NOTES ON THE DESIGN OF SEWAGE DISPOSAL WORK

BY

F. C. TEMPLE, Member.

A student of books and papers on sewage disposal works must be impressed by the amazing variety, not only in the methods of sewage disposal but also in the methods of thought with which sewage disposal problems are approached or discussed, and by the absence of any generally accepted criterion on which the design of sewage disposal works is based. Descriptions of different sewage disposal works differ so entirely in the information given that they might very well be thought to be dealing with entirely different subjects, and curiously enough the analyses of the sewage to be dealt with vary so much that at first sight the problem of its disposal appears to be different in essentials: and yet the problem of sewage disposal is substantially the same all the world over.

The problem is the oxidisation and nitrification of the putrefactive constituents of animal excreta to harmless non-putrefactive compounds without giving rise to any nuisance in the process. Modern social conditions are such that for practical purposes it is the oxidisation and nitrification of human excreta.

Within certain fairly well defined limits, the average quantity and quality of excreta produced per head is the same everywhere. The scope of each particular sewage disposal problem should therefore be expressed in terms of the number of persons served, and the first thing to be ascertained in dealing with any sewage disposal problem is the number of persons whose excreta is to be rendered non-putrefactive or in other words the number of persons to be served.

But the number of persons served is by no means always stated in a description of sewage disposal works. It is very common to find the remark that the sewage under consideration is strong or average or weak. In a list compiled from a large number of publications containing 81 descriptions of sewage works or classifications of sewage, only 55 give the number of persons served, only

39 give any definite indication of the class of sewage by stating the strength of the sewage in gallons per head, and 18 more by giving an analysis of the crude sewage and the population or the total quantity per day.

A perusal of this list will show how varied is the information given in different descriptions of sewage works. Hardly any two items are alike and scarcely any give all the information that is desirable, and the difficulty of comparing one installation with another is immense in consequence.

The data most commonly given are:—for broad irrigation, or treatment of crude sewage direct on land, thousand gallons per acre per day: for detritus tanks, sedimentation, septic and activated sludge tanks, either period of rest, or gallons capacity per day: for contact beds, period of contact: for trickling filters, gallons per square foot of area, or less commonly gallons per cubic foot of filtering material: and for storm tanks, so many hours flow, or so many times the average dry weather flow. Analyses are usually given in parts per 100,000. Unless the strength of the crude sewage is known, it is impossible to compare the efficiency of two systems, for if two similar systems are working equally efficiently on sewages of different strength, the analyses of the final effluent will vary according to the degree of dilution of the crude sewage.

The use of sewage data in this form implies the fundamental error of regarding the water mixed with the sewage as the sewage itself whereas it is the vehicle in which the sewage is conveyed. The quantity of water mixed with the sewage, or more briefly the extent of dilution of the sewage makes a profound difference in the details of the sewage disposal apparatus, but the underlying principle is the same, namely, that for every person served a certain amount of putrefactive matter is to be oxidised and nitrified.

The essential function of any sewage disposal system is the reduction of unstable putrefactive organic compounds to stable non-putrefactive compounds. In all systems except trenching, incineration and broad irrigation this is done partly by mechanical and partly by biological means. The mechanical part of the operation consists in separating the solids from the liquids, and the biological in oxidising and nitrifying the unstable compounds in the liquids. In almost every form of disposal works, the mechanical separation is not completed in one operation, but is carried on in a series of operations.

The first of these operations is the extraction of large floating solids other than faeces, such as sticks and vegetable matter, by means of screens, and of mineral grit, chiefly road material, by

settlement. Very few installations except Indian Septic tank latrines omit screens and detritus tanks or grit catchers.

The second operation is the separation of the solids and liquids of the sewage proper. The apparatus for performing this operation is extremely varied in form. The simplest form is the sedimentation tank which either keeps the sewage at rest for a certain period, or reduces its velocity to such a point that the solids settle as sludge. This process is sometimes assisted by chemical precipitants. It aims at extracting the maximum quantity of solids which being in a highly putrefactive condition have to be barged out to sea or buried. Any possible manurial value in the sewage is lost by this method. The next form is the septic tank, or liquefying tank, the details of which are extremely varied, from the simple Cameron or Clemesha pattern, to the Travis Hydrolytic tank, or the Dibdin Slate Beds, which present large surfaces to attract floating matter. These tanks produce much less sludge than mere sedimentation tanks; but the sludge is more or less offensive and of little manurial value, and therefore not easy of disposal, unless further treated. The liquid effluent, freed as far as possible of the suspended solids with their organic contents, must be subjected to a further treatment to oxidise the organic matters in solution into harmless compounds which will not putrefy, or if discharged into a stream take up oxygen in more than a certain proportion from that stream. This treatment may be directly on land which is irrigated and slightly fertilized by the effluent, or on bacterial filters, the effluent from which can also be used with some advantage for irrigation. Recent design shows a tendency to sub-divide the separation processes, as in Jameson's system at Pretoria where the liquid is taken from the first tanks straight to filters, and the sludge is taken out daily to other digestion tanks where a further separation takes place, the liquor and solids being finally disposed of on land, the liquor by irrigation and the solids as manure. Here the manurial value is appreciable.

One process differs from all these, namely, the bioaeration process, in that it combines the separation of the solids with the oxidisation of the liquids in the same operation. The forms taken by the process are already varied, and new varieties are still appearing. The essential feature of the process is that if sewage is agitated in contact with air, and the sludge settled out and mixed with fresh sewage, and that mixture is again agitated in contact with air, an action is set up which not only settles out the sludge very rapidly as a flocculent precipitate but also oxidises and nitrifies the effluent. Both effluent and sludge from this process have very active fertilising properties.

The method to be employed for the disposal of any particular sewage must be selected to suit the character of the sewage and local conditions. Many factors must be considered. The first is the quantity of the true sewage. This depends directly on the number of persons in the locality. Next comes the method of collection and removal of the sewage from the residences to the disposal site, which may be by hand and cart or by water in sewers; and then the final destination of the products of the disposal system which will be absorption in land or water.

The simplest form of all sewage disposal though the most primitive is entirely satisfactory. It is the burying of each individual's excreta in the ground in a different place each day where the bacteria resident in the upper layers of the soil will decompose and oxidise and nitrify it. This method is entirely satisfactory as long as the quantity of sewage buried in any one place does not exceed the purifying capacity of the soil immediately surrounding it. It requires a small amount of water in the soil. Sewage buried in pure sand is sometimes robbed of its own moisture to such an extent that the oxidising and nitrifying organisms appear to be unable to deal with it. It is then reduced to a very offensive mass which may last almost unchanged for very long periods.

This method is only possible in a scattered community and among primitive people (who usually spoil it by omitting the burying part of the process). Civilisation, with its requirements of privacy and decency, makes the enclosed privy a necessity. The privy itself may be a movable structure placed over a new hole in the ground each day or its contents may be removed daily. (In some places the hole is made large and the removal only made at long intervals). As each privy is certain to be made to serve more than one person, the quantity of sewage collected together becomes sufficiently large to require care as to how and where it is buried. As the community grows and the quantity of sewage increases, it becomes necessary to organise a conservancy system, by which the sewage is buried in a properly managed trenching ground

An alternative method of disposing of sewage removed by hand from privies is by incineration. This is expensive except where fuel is very cheap: it is not very easy to handle so as to avoid aerial nuisance: and is scarcely practicable on a very large scale.

All these methods deal with the sewage in its crude, undiluted and (a point worth noting) unadulterated state. They are the methods applicable to towns in which (as in most towns in India) there is no piped water supply, and generally no very large quantity of water available.

After this brief review of the methods of dealing with undiluted sewage, the remainder of this paper will discuss the problems of dealing with sewage diluted with greater or less quantities of water and the term sewage will be used for the sewage so diluted.

Between the hand removal methods described above and complete water borne sewerage leading from house to outfall there remains the intermediate stage of hand removal to water flushed dumping pits, connected either into sewers or into septic tanks. This method is very common in the few towns in India which have yet installed any form of sewerage system. The main reason for not connecting individual houses is want of money. Most Municipalities in India are very poor and when the prejudice, which still unfortunately is very strong, against underground sewers is overcome, it is rare that anything more can be done for the money than provide a skeleton system of sewers, serving water flushed public latrines and dumping pits. And even in those streets where sewers exist, few householders will spend the money necessary to connect. Where dumping is done, the dumping pits are usually connected to the sewers. In some of the very flat towns in the plains, for reasons of economy, the sewers are laid at such flat gradients that they will only carry tank effluent and not crude sewage. In these systems the dumping pits connect direct into septic tanks. And by means of them, in the town of Gaya, an opportunity occurred to ascertain the minimum dilution of sewage necessary for its treatment in septic tanks.

When the Gaya septic tanks were first started up, the dilution in some of them was only one gallon per head. These tanks became choked with a floating semi solid mass of almost unchanged faeces and the effluent was an extremely offensive, highly putrefactive liquid. At three gallons dilution more action began to take place; but it was not until 5 gallons was reached that the floating mass of undigested faeces changed to the characteristic healthy scum of a good septic tank and the effluent became such as could be passed on without appreciable nuisance.

Precisely the same experience was obtained from a septic tank latrine at Patna.

When more water is available any dilution from 5 gallons up to 40 gallons per user makes a sewage for which several simple forms of septic tank work almost equally well.

When the dilution increases above about 40 gallons per head, the solids become so much broken up and so finely divided that it is difficult to bring them sufficiently to rest for the necessary action to take place without over septicisation occurring.

At the same time, speaking generally, the weaker or more dilute the sewage, the easier it is to purify. If it is sufficiently dilute the oxygen and other natural purifying agencies in the air and water will purify it without any further treatment, and we arrive at disposal by dilution. Thus the two ends of the scale offer the two simplest forms of disposal. At one end the neat sewage undiluted with any water is put in relatively small quantities in the earth. At the other the sewage is mixed with a volume of water relatively so vast that nothing further is required.

Except in a system operated only by hand removal and dumping direct into septic tanks supplied with clean water, no sewage will ever be unadulterated. In all water borne sewerage systems, some foreign matter, such as road grit and other mineral substances, and kitchen refuse, slops, and other organic matter, and in many places trade wastes will find their way into the sewers and so to the disposal works. Even in an Indian Septic tank latrine, some road grit, brought to the seats by the feet of the users, will come in, and in a completely "separate" European system, there will be paper, and in both some rags.

An Indian Septic tank latrine is so nearly grit free that the grit which enters is insufficient to cause trouble. An ordinary "separate" system of sewers will absorb enough grit through slop sinks and yard gullies, even though those are designed to exclude rain water, to make its removal desirable. A partially separate system which is probably the best form of sewerage for most Indian towns has enough grit to make its removal very desirable and a combined system will contain so much as to render its removal essential, if the disposal works proper are to act satisfactorily.

In addition to grit which will settle, the sewage will contain bits of wood, rags and the like, most of which will float, which would also interfere with the action of any tank. These are best caught on screens and removed by means of rakes of some kind. These arrangements are often offensive, especially when the sewage is already old and septic. The fresher the sewage when it is screened, the smaller the trouble in dealing with the screenings. (This remark applies to all operations in handling sewage. It is worth a great deal to be able to deal with sewage before any part of it can become septic. In the Tropics the sewage should, if in any way possible, not be more than twelve hours old. In temperate climates the time limit is probably longer). The screens should stop only such matters as will interfere with the working of the tank. Two simple bar screens, the first with one inch openings, and the second with half inch openings, will usually do all that is required.

To extract the grit, detritus tanks or grit catchers are provided. These should not be confused with the first compartment of a Clemesha Pattern Septic Tank, which is often called the Grit Chamber. It obtained the name because the baffles which enclose it were first placed with a view to catching grit.

Detritus tanks or grit catchers are discussed most frequently in terms of period of rest or in parts of the dry weather flow. Kershaw gives 1/100 to 1/200 of the D. W. F. A very few writers are beginning to discuss velocities through them. As their sole purpose is or should be to extract mineral grit, cross sectional velocity of the sewage is the most important consideration. The velocity of the flow must be reduced sufficiently low to bring down all the grit that is likely to interfere with the working of the tank, and the time taken to pass through the grit catcher must be sufficient for the grit to drop. It must not however be long enough for septic tank action to proceed far, (this cannot be avoided entirely, for indeed it always begins in the sewers) or for more than the inevitable small quantity of putrefactive sludge to settle.

It is most important that there should be no pockets or corners in which small quantities of sludge may rest long enough to become septic. If that occurs, septic action is set up rapidly in the sewage, which disturbs the action of the disposal works, and sooner or later causes aerial nuisance.

A most interesting grit catcher is that evolved by F. W. Jameson at Pretoria. It is nothing but a length of the sewer widened out with a flat bottom 6 ft. wide with nearly 2 cu. secs. of sewage flowing through it, 4″ deep which means a velocity of about 1 ft. per sec. for a distance of 27 ft. 6 in. Presumably a velocity of 9″ to 15″ per second will be about right. It is sad that none of us who have so often seen defective surface drains in India catching grit in this very way, should have thought of it. There are now grit catchers of this pattern working well in India.

A common form of grit catcher is a hopper shaped chamber with the sewage entering at the centre and discharging over a circular peripheral weir. It is probably better to bring the sewage in on a tangent at the circumference and decant the liquid at the centre through a bell mouth and bent pipe. The spiral movement given by the tangential entry allows little chance of stagnation of the liquid and the consequent septic action. A screen can be fixed round the bell mouth, so that grit catcher and screening chamber can be combined in one. Such a conical grit catcher can reduce cross sectional velocity to less than 0.1′ per sec. and yet leave the sewage with only 30 minutes rest in the hopper. Either form of

grit catcher may be considered as only an enlargement of the sewer, and unlikely to set up any serious septic tank action. The conical grit catcher is cleaned by means of a sludge pipe similar to that in an Imhoff tank rising from the lowest point of the hopper.

Grit catchers should always be provided in duplicate, so that they can be cleaned regularly without interfering with the routine of the works.

After the sewage has been freed from floating foreign matter by the screens, and from mineral grit by the grit catchers, it undergoes treatment in some form of tank.

In spite of the fact that about 1860 the "Mouras Automatic Scavanger," probably the first true septic tank, was inaugurated in France and proved steadily satisfactory up to a certain point, and at the same time experiments on upward filtration in place of chemical precipitation in Europe and America gave promising results, yet sedimentation tanks usually with chemical precipitation were very largely adopted.

Sedimentation tanks pure and simple appear to have no true merits whatever. They aim at bringing down as much solid matter as possible, so that by some mechanical means it may be thrown away where it will cause no nuisance. No attempt is made to liquify or purify any part, or to conserve the nitrogen in the sewage. As far as published records indicate there are none in use in India, and it is to be hoped that there never will be. The only excuse for such a method is to be found in very large towns such as London and Glasgow where the sewage problem is so colossal, and the quantity of sludge so enormous, that until some system of making the sludge into a marketable commodity, or of reducing its bulk to such an extent that the saving in cost of removal will pay for the reconstruction of the plant, a method which actually works must continue to be employed.

The Mouras Automatic Scavanger appears to have failed to gain popular favour because a non-putrefactive effluent was not obtained from it.

Seeing that it was really only a form of septic tank, we know now in the light of experience gained since then that it could not be expected to yield a non-putrefactive effluent; but that its effluent would have to undergo an oxidising process in some form of filter or contact bed before it could become non-putrefactive.

A great deal of work was done during the next 30 years on filters of various designs. The difficulty of keeping filters clear,

and from becoming choked with solids led to experiments with various designs of settling tanks. In 1895 Cameron inaugurated his septic tank at Exeter. Following on that came a wonderful variety of tanks, septic tanks, settling tanks, hydrolytic tanks and others, all designed to prepare screened and grit free sewage for final filtration of the effluent and disposal of the sludge. As they are all engaged on the same task with approximately equal results, there must be some general principles governing their action, which should regulate their design.

In searching for these general principles it is necessary to recognise that the action of any tank for sewage disposal is and must be partly mechanical and partly biological. Some people attend chiefly to the mechanical action of sedimentation and others to the biological actions which produce chemical changes. But no sedimentation tank can avoid all biological action, and every biological tank is sure to promote some sedimentation.

After the sewage has been freed from floating refuse by screens and from most of the mineral grit by the grit catchers, it may be considered to consist broadly of (1) floating solids, (2) settling solids, (3) liquid more or less free from solids. The removal of the solids and the delivery of the liquid as free from solids as possible is the essential function of every tank.

If the action were purely mechanical some form of decanting apparatus which would draw off the liquid most free from solids would be all that is required. But chemical and biological changes in the floating and settling solids make part of the former settle and part of the latter float and by the formation of gases are liable to keep much solid matter in movement throughout the tank, so that at no point is the liquid very free from solids.

A perfectly plain rectangular or cylindrical tank some 7′ deep in which outlet and inlet were situated some 3 ft. from the surface would retain much of the solids, though not enough to make final treatment of the effluent easy.

Cameron's Exeter tank was not very much more than this, except that it began with a "grit chamber" 10 ft. deep by 7 ft. long by 18 ft. wide through which the sewage passed over a wall submerged 1 ft., into the main tank 18 ft. wide 7 ft. 6 in. deep and 56 ft. 10 in. long.

Clemesha in "Sewage Disposal in the Tropics" describes his experiments on septic tanks. His tank is very like Cameron's, and contains a "grit chamber" bounded by a submerged wall. To catch undigested faeces, jute and other floating substances, he

introduced a hanging partition, previous to the submerged wall, reaching down from the surface to within 18″ from the floor. His experiments, confirmed by subsequent practice, show that a very great change takes place in this compartment of the tank: that the hanging partition is of far greater importance than the submerged wall: and that its content should be about one-eighth of the content of the whole tank. In this chamber the floating solids are necessarily retained until they are so changed as to sink. Some part of them sinks finally and remains at the bottom; for sludge has to be removed from this chamber from time to time. No doubt there is a good deal of movement in the sludge owing to the development of gases. The forward movement of the sewage carries on some of the solids, principally those particles that have a tendency to come down slowly or scarcely to settle at all. If the size of the whole tank is correct for the work it has to do, and the first compartment bounded by the hanging baffle is one-eighth of the whole, the accumulation of floating solids will be found to increase until it is some 2 ft. thick, and then remain about constant, the chemical and biological changes removing as much solid as is brought in.

The total size of the tank is of supreme importance.

As far as information is available, the only published account of experiments definitely directed to determining the best size of septic tank is that given by Clemesha in "Sewage Disposal in the Tropics."

The conclusion arrived at in those experiments is that a period of 72 hours (or 3 days) rest in the septic tank gives the best results on a 5 gallon sewage.

It is to be noted that Clemesha discusses the size of the septic tank in terms of period of rest. But he makes the all important qualification that this period of rest is for a 5-gallon sewage (that is a sewage diluted with 5 gallons of water per user per day). In other words the tank capacity is 15 gallons or 2.4 cu. ft. per user.

In 1915 when asked to advise on the size of filters for the Patna General Hospital Sewerage System, he said that for each user there was a certain quantity of putrefactive matter to be oxidised and nitrified and that this required a certain quantity of filtering material irrespective of the dilution.

This argument used by Clemesha, that the necessary size of filters depended on the number of users appeared to be logically applicable to the septic tank also. Though unfortunately there has been no opportunity to study the question by precise laboratory experiments, the practical working of a number of installations designed and operated on those lines has proved this to be true.

A most practical example of the correctness of this reasoning is to be found in a septic tank of four compartments serving some 8,000 persons. This tank was giving bad effluents and causing much nuisance and was believed to be overloaded. Proposals were actually made for enlarging it.

The characteristic signs of over-septicisation were however recognised and as its capacity was about 4 cu. ft. per user, a recommendation was made to reduce its capacity by half. Two compartments were thrown out of use, and the tank subsequently worked very fairly well for several years.

The practice of discussing the size of tanks in terms of the period of rest is nothing but a bad habit which should be given up. It clearly arose in the early days of Cameron's Septic tank at Exeter before it had become the practice to distinguish clearly between sewages of different strength. The period originally adopted namely 24 hours was necessarily purely arbitrary. For many sewages it was too long, and the septic tank fell into discredit in consequence. About 1911 a paper in the supplement to the Journal of the Royal Sanitary Institute said that septic tanks were entirely discredited and useless. At the same time Lane Brown and Hewlett in Lucknow were stating that septic tanks with a maximum period of rest of 8 hours were satisfactory.

G. B. Kershaw in "Sewage Purification and Disposal" writes as follows:—"The capacity of septic tanks will vary somewhat according to the nature of the sewage to be tanked. It was formerly the custom to make the tank capacity equal to a 24 hours flow of sewage: and in India it appears that a three days' flow has on occasion been found advantageous."

"In this country (England), from 12 hours to 24 hours is a very usual capacity but much depends upon the distance the sewage has travelled before entering the tanks."

The fact that from 12 hours to 24 hours rest has been found suitable in England is due to the fact that the average English sewage is approximately of the same average dilution, and therefore requires the same average tank capacity. A latitude of 100 per cent however in the size laid down indicates a lack of precise thought on the subject.

Metcalf and Eddy in their three volume work on "American Sewage Practice" are scarcely more explicit. They give detailed analyses both particular and average of various sewages, and it is true that they state the dilution of each sewage. But they say of the analyses that "their chief value is illustrative and as guides in making estimates of the probable quality of sewage from a community of known size and character." They give little in the way

of definite recommendations as to the size of the tanks. For sedimentation tanks they say the best period may vary from 30 minutes to 4 or 6 hours: in septic tanks the detention period is "in general from 8 to 24 hours: for Imhoff tanks (which they classify as distinct from septic tanks) "the practical detention period appears generally to be not over 4 hours." Seeing that they are dealing principally with the much diluted American sewages, this last conclusion agrees with the reasoning above. A 75-gallon sewage will have a 4-hours detention period in a tank having a capacity of 2 c.ft. per user.

The distance that the sewage has travelled before entering the tanks has a very important bearing on the design of the tanks. Clemesha's figure of 15 gallons or 2.4 c.ft. tank capacity per user is for a septic tank latrine where the sewage enters the latrine absolutely fresh. Where the sewage has travelled through sewers rather less capacity is preferable. Good results are usually obtained with 2 c.ft. per user with sewage not more than 12 hours old. Sewage such as that which reaches the Lovegrove pumping station at Bombay is already so old and septic when it arrives that it would be difficult to design any septic tank which would treat it satisfactorily.

It has already been stated that the minimum dilution for biological treatment is 5 gallons per user. From 5 to 10 gallons dilution gives a practicable sewage, which however requires constant watching, for the presence of grit or other foreign matter, if any happens to pass the grit catchers and screens, may easily disturb the working of the tank.

From 10 to 35 gallons dilution gives a sewage that is very easily treated in almost any form of septic tank. The experiments in Patna on five different patterns of tank all treating a sewage within these limits showed that for Indian conditions the very simple Clemesha pattern tank is at least as satisfactory as any other.

When the dilution rises above 40 gallons per user, the rate of flow through a Clemesha pattern tank designed for 2 cu. ft. capacity per user becomes so great that the solid matter is broken into small particles and carried through in suspension before sufficient time has elapsed for the necessary changes to occur. When the sewage is so dilute, it is clearly necessary to use a different form of tank. Merely increasing the size of the tank over and above the correct figure for the number of users will produce over-septicisation with all its attendant troubles. The solution is very probably to be found in the use of separate tanks in series on the lines indicated

by F. W. Jameson in his recent paper on "Evolution in Sewage Disposal—with special regard to South African experience in sludge treatment, particularly at Pretoria."

An examination of what occurs in a Clemesha tank supports this view. For Indian sewage not more than 12 hours old between 5 and 40 gallons dilution a Clemesha tank designed as follows can be relied on to give good results. The total capacity up to top water level must be 2 cu. ft. per user. The average depth to top water level must be 6 ft. (average depth is stated as it is convenient to slope the bottom 1 in 30 to the sludge out valve). Except in very small tanks the length should be eight times the breadth. There should always be a hanging baffle one-eighth of the length of the tank from the inlet, extending to within 18 ins. of the floor. The inlet must be in a downward and a backward rather than forward direction delivering 2 ft. 6 in. below T. W. L. In a big tank it is convenient to place a standing baffle 4 ft. high about 3 ft., beyond the hanging baffle. If this is done there should be two sludge out valves one on either side of this standing baffle, and the floor must slope down to the sludge valves 1 in 30 in the long tank and steeper in the small tank or so-called "grit chamber." In recent installations the standing baffle is raised to form a weir separating the two parts of the tank. Except in very small installations, for which a different design is necessary, the requisite tank capacity for the number of users should be made up in separate parallel units. The minimum practicable size of this type of tank is that to serve 95 to 100 persons and is 2 ft. wide 16 ft. long and 6 ft. deep. Practical considerations render a single tank necessary until about double this capacity is required. 190 to 200 persons may be served by one tank 2′—10″ × 22′—6″ × 6′ or better by two parallel tanks of the minimum size. The maximum practicable size of individual tank is that to serve about 1,000 persons being 72′ × 9′ × 6′. Larger tanks can be made and worked; but when greater capacity is required more efficient working will be obtained from a larger number of smaller parallel units.

When the fresh sewage enters, the floating solids which are mostly faeces rise to the surface and are retained by the hanging baffle. As the changes in the solids occur a separation process takes place, a small amount settling as heavy sludge, and the bulk sinking enough to pass under the hanging baffle into the second compartment. There further changes occur and a further separation takes place, part of the solids forming a scum which has an earthy appearance and may become thick and solid enough to support a growth of grass and even tomatoes, and part sinking to form a sludge. In a properly designed and operated tank a good deal of sludge digestion certainly goes on, for the quantity of sludge

that collects permanently and requires removal from time to time is remarkably small. The sludge digestion must give rise to the formation of gases; but these are not sufficient to break the scum, and presumably they gradually percolate through its spongy mass and escape in that way.

The outlet from this tank is usually over a weir protected at a distance of about 6 to 12 inches by a scum board which must dip 2 ft. 6 in. below T. W. L. The space between the scum board and the weir should be kept free by manual labour from the small pieces of scum which will float up there.

In a tank of this kind an experienced eye can judge approximately how well the tank is working by the state of the scum and the clearness of the effluent. A good healthy scum is found with an effluent comparatively clear and free from solids. Over-septicisation will dissolve away a scum with extraordinary rapidity, and is indicated by absence of scum, effervescence in the tank, usually an offensive smell, and grey or black filamentous pieces of sludge in the effluent. Excess of dilution water over and above the maximum limit per user for the tank will be indicated by absence of scum except occasionally in any still corners of the tank, and much suspended solid in the effluent consisting of wholly or partly undigested faeces broken small. Lack of dilution water without over-septicisation will be indicated by a floating mass of almost unchanged faeces and a foul highly coloured effluent.

The two-storied septic tanks such as the Imhoff, or the Travis, have this in common with the Clemesha that they retain the floating solids, the liquid being drawn off from a level below that reached by the floating solids. They differ principally in the fact that the baffles are partly longitudinal and partly horizontal instead of entirely transverse. The baffles are so arranged that as heavy sludge settles it drops through slots past which it cannot rise again to interfere with the clarified liquor.

Such precise proportions as those laid down for a Clemesha tank do not appear to be available for two-storeyed tanks. The indications are however in favour of making the upper chamber about one-third to one-quarter of the total instead of the one-eighth laid down for the first chamber of the Clemesha. The reason that it can and should be made larger is that the more complete isolation of the sludge helps to clarify the liquor more readily, and the time necessary for the breaking down of the original faeces of the first chamber, and for the changes to scum, liquor and sludge of the second chamber, has to be provided for the liquor which flows straight through the single upper storey.

In Jameson's system at Pretoria, the first tank which he calls a Watson tank has a capacity of 1 c. ft. per user. The liquor from this is taken direct to filters. The sludge is also drawn off daily to sludge digestion tanks in which the usual process of separation of floating solids, liquor and settling solids goes on. This complete removal of the successive separation processes into distinct separate tanks is almost certainly an improvement mechanically, and is probably an improvement bacteriologically.

It is probable that the subdivision of the separation processes in this way is the solution of the problem of clarifying sewages more dilute than 40 gallons; but at present no definite data appear to be available as to the best proportions of the various parts. Certain points alone are evident: the sewage must be brought sufficiently near to rest for floating solids to rise and settling solids to settle and remain comparatively quiescent: sufficient time must be allowed for the chemical and biological changes to take place: and sludge and liquor must be drawn off separately before over-septicisation (which is really a form of putrefaction) has time to take place.

The total tank capacity required per user is probably about the same. In order to reduce velocity through the tank, the cross section must be increased, and that means that the length must be diminished. As in a straight tank a certain distance of travel is necessary to permit the fall of the solids, the indications are in favour of the circular hopper shaped tanks in which the flow is spiral.

The discussion of bio-aeration tanks using activated sludge is held until after that of filters as they combine the work of both tank and filter.

Tank treatment, except by a bio-aeration process, is not the essential part of sewage disposal. Tank effluent is still putrefactive and not fit to be let loose in a stream, or on land indiscriminately. As stated at the beginning of the paper sewage disposal is the oxidisation and nitrification of the putrefactive constituents of the sewage. Tank treatment prepares the sewage for this oxidisation and nitrification either on land, or in a relatively very large volume of water, or on filters. Doubtless the Mauras Automatic Scavenger would have found favour if it had been realised that its effluent needed further treatment in a filter, which is the only really essential part of the whole biological process.

It always is desirable to have the liquid to be oxidised on the filter as free from solids as possible, and in some installations there is introduced an upward flow tank filled with coarse filtering material sometimes called a Macerating tank between the septic

tank and the filter. Some research on them was done in Poona. These were found very useful at Patna, though those installed there were too small. Monk in Calcutta patented an almost identical arrangement which he calls an anaerobic filter. His filters have not been studied with much scientific precision and the best size of macerating tank remains to be decided. Information available suggests approximately the same size as the septic tank served. A convenient form of macerator is a tank filled with 1″ to $1\frac{1}{2}$″ ballast resting on a false perforated bottom, made so that the flow of septic tank effluent is from the bottom upwards, and the tank can be washed out from the top downwards. It is a cumbrous arrangement and if a separation of the septic tank into a sedimentation and scum catching tank first, followed by the filters on the one hand and a sludge digestion tank on the other will deliver liquid almost free from solids at the filters, it is probably an improvement.

On the subject of filters there is much literature and very little unanimity. As in the tanks that precede the filters the action in the filter is partly biological and partly mechanical. The biological action is the essential work of the filter. The mechanical action is the straining out of such solids as come over in the tank effluent. If an effluent could be delivered from the tanks to the filters entirely free from suspended solids it would be much easier to design a filter which would give an entirely satisfactory final effluent.

The designs of filters are various. They all aim at providing as suitable as possible a habitat for the bacteria which bring about the necessary biological changes. Experience has shown that this is best provided in the form of rough surfaced material broken in the form of ballast so as to present as large a surface area as possible, for it is in the rough surface of the material that the bacteria thrive best.

The bacteria require an ample supply of oxygen. In the method of supplying this, filters fall into two main subdivisions, contact beds and trickling filters. Contact beds are water tight tanks filled with the filtering material, which being in the form of broken brick or stone ballast or coke breeze provides interstices which can be filled with tank effluent. The method of operation is to fill the tank with tank effluent: leave it standing full for a given period, say 2 hours: empty it out as completely as possible thereby drawing down fresh supplies of air into the interstices of the filtering material: leave it empty so as to become thoroughly aerated for a certain period, usually two to three times the period of contact: and then repeat the process. Trickling filters are usually made of an impervious floor draining to an outlet on which is heaped a pile of ballast or breeze. The tank effluent is spread or

scattered by some mechanical distributor over the surface of the filter. As it sinks down through the filter it carries down with it fresh supplies of air to the bacteria resident in the filter. The size of filter used in various places varies from about 3 c.ft. per user to 12 c.ft. per user. There is usually very little reason given for the particular size chosen, and it is very rare to find the size expressed in terms of the number of users. It is most common to find the size of filters expressed in terms of gallons of liquid treated per unit of surface area. Clemesha as noted above states that they should be calculated in cubic feet per user. Fowler in "Septic Tanks in Bengal" discusses the number of gallons to the cubic yard, but also mentions the quantity of filtering medium per person. Kershaw discusses the quantity of sewage that can be treated per c. yd. of filtering medium and notes that greater quantities of American sewages can be treated per cubic yard. He observes that this may be due to the sewage being more dilute. Metcalf and Eddy give no indication how they calculate the size of filters.

C. Whittaker's experiments in 1897 at Acrington and many others subsequently showed that for the same volume per sq. yd. of surface a deeper filter gave a better effluent than a shallow one. The Horfield experiments showed that with the same volume of sewage per cubic foot of filtering medium there was very little difference between a deep and a shallow filter.

Turner and Goldsmith in "Sanitation in India" say "The amount of sewage which can be purified per cubic yard of percolating filter varies within practical limits, nearly inversely as the strength of liquor treated."

These all support Clemesha's argument that the cubic content of the filtering medium must depend on the amount of putrefactive matter to be oxidized, or in other words on the number of users.

Much depends on what is to be done with the effluent. If it can finally be absorbed on land or let go in a considerable body of water 3 c.ft. per user is enough for a reasonably clear tank effluent. When more complete purification is required the size of the filters must be increased.

There has recently been much discussion regarding the best depth for filters. Practical experience indicates from 5 ft. to 7 ft. as the easiest to work. Less depth than 5 ft. may not be sufficient to spread the liquid out in a fine enough film over the surface of the particles of the filtering medium with the result that oxidation and nitrification are not carried far enough. Greater depth involves a loss of head that can rarely be spared. Deep filters cost rather less than shallow ones to construct as the masonry floors on

which they rest are smaller in area; but they are rather more expensive to maintain. If more purification is required than can be produced by 3 c.ft. per user, a rather better effluent will be obtained in practice by making the sewage flow through a series of filters each giving 3 c.ft. per user than by spreading the sewage over a series of beds in parallel. This involves double or more loss of head which is not always available.

The grading of the filtering material must depend on the quality of the tank effluent and the nature of the material available. The best possible effluent is given by a sand filter very similar to that used for water works. But such a filter cannot be used in practice because the sand layer will choke much too rapidly.

For an average tank effluent the size of the top layer of filtering material should be about half-inch cubes, that is, roughly, material which will be rejected on a screen of 2 meshes to the linear inch and will pass a screen of 1 in. mesh. There is not much to be gained by grading the material in different sizes except that the bottom 6 ins. layer should be rather larger in order to provide a free passage for the final effluent to flow away over the floor. If the tank effluent is very well clarified, the top 12 ins. of the filter may be made of smaller grade ballast, lying, for instance, between $\frac{1}{4}$ in. and $\frac{3}{8}$ in. mesh. If double filtration is employed, the second filter will give more satisfactory results if it has a rather fine layer of this kind. The layer underlying the fine layer must be composed of pieces not larger than 4 times the size of the pieces in the fine layer It is better however to use rather smaller pieces than that.

Grading in a water works filter aims at giving as large a passage for the water in the lower layers as is consistent with keeping the sand in its place. The relation of one grade to another can be demonstrated mathematically without any difficulty. Roughly it may be taken that the diameters of the pieces in each successive layer should bear the relation of 1 to 4. In sewage filters three objects ; have to be considered (1) keeping the material in its place, (2) providing ample passage for the effluent and (3) providing the maximum possible habitat for the nitrifying bacteria. To satisfy conditions (1) and (2) the relation of 1 to 4 is satisfactory. To satisfy (3) it is better to make the relatoin 1 : 2 or thereabouts.

In the course of this paper frequent reference has been made to the peculiarity of the bio-aeration process. Its most important peculiarity is its property of combining some of the separate processes previously described in a smaller number of processes. There are many forms of bio-aeration plant already in existence and more are appearing at intervals. The essential purpose of them all, as with

all other disposal systems, is the separation of solids and liquids and the conversion of both from unstable to stable chemical compounds.

The underlying principle on which all the systems of bio-aeration are based is that if sludge settled out of sewage that has been agitated in contact with air for a sufficiently long period is mixed and agitated again in contact with air with fresh sewage, the solids in the fresh sewage will rapidly change into a flocculent precipitate, and at the same time the liquid will be oxidised and nitrified to stable non-putrefactive compounds.

As in the other processes, the sewage must first be freed from mineral grit and floating refuse other than faeces. This can be done in any ordinary form of detritus tank or grit catcher. In some installations, the detritus tank is agitated with air in the same way as the sewage in the aeration tanks. If a little activated sludge were admitted at the same time, the silt would undoubtedly come down very quickly; but a good deal of organic matter might come down with it too, the proper place in which to come down is in the settling tanks. The particular form of detritus tank or grit catcher must be determined for each particular installation. The grit-free sewage is then admitted to the aeration tanks.

There are already many forms of aeration tank. In all of them the sewage is given a forward and also a rotary movement. Three typical forms are as follows:—(1) Activated Sludge, Ltd.—The sewage is admitted into the end of a channel about 6 ft. deep and 3 ft. wide which is folded backward and forward on itself so as to make a compact structure. All along the middle or one side, of the channel at the bottom are diffusers through which air is blown. The air imparts to the sewage an upward and rotary movement across the channel. The channel is divided by baffles into short chambers, the passages from one chamber to the next being through a comparatively small hole at the bottom, just over the diffusers. The baffles prevent the possibility of direct short circuiting from one end of the channel to the other. At the end of the channel the sewage passes into a settling tank with a hopper-shaped bottom. The clear liquid is here decanted off through bell mouths. From the bottom an air lift leads to a short length of channel known as the sludge re-aeration tank. The air lift brings the sludge from the hopper to this tank from which it overflows into the aeration tank at the same point at which the crude sewage enters. The incoming sewage imparts a forward movement to the sewage in the tank in proportion to its volume, and a further forward movement is given by the re-aerated sludge, returned by the air lift. The quantity of effluent drawn off by the bell mouths is equal to the quantity of

crude sewage that enters. Recent systems are working with aeration tanks 12 ft. deep.

(2) Haworth's paddle wheel system is somewhat similar except that instead of agitation and aeration by compressed air the sewage is forced along the channels which are about 3 ft. deep at a velocity of 1½ to 2 ft. per second. The oxidisation of the sewage depends for its air on surface aeration, similar to that which takes place in a river. In this system the aerating channel is continuous and the settling hoppers are placed to one side, so that all the forward movement of the sewage is not necessarily down through the hoppers and up again. The lift from the hoppers is by a pump which returns the sludge to mix with the incoming crude sewage.

(3) Bolton's "Simplex" system is very different, though it also relies on surface aeration. The aeration tank is hopper-shaped. It has a funnel and pipe leading up in the centre, from which revolving flippers send the liquid in a spiral over the top of the funnel which is about three inches above the surface of the tank liquid. The liquid is thus circulated about once every 15 minutes. In one form of this tank, settlement is made to take place in the tank by the construction of a hanging baffle across the corners leaving triangular spaces up which the clear effluent rises and passes out over a weir. In this way the return sludge lift is abolished. Further experiments on this method should be very interesting, as in an installation of two or three tanks, there are many variations possible. They could be used in parallel or in series, or half and half, some of the sewage being thrown by the flippers into the same tank and some into the next.

In all forms, the work performed here in one operation is that performed in other methods, by both septic or sedimentation tanks, and filters. If the bio-aeration plant is properly designed and operated, it completely separates a clear effluent from all suspended solids, and delivers it bright, clear and non-putrefactive. It also delivers the sludge in an inoffensive condition. This sludge has often a very high manurial value and is very easily mixed with the soil and absorbed by vegetation to which it sometimes gives an amazing growth. The problem of drying the sludge as a practical operation is not yet solved, though small quantities can be dried without difficulty.

In descriptions of bio-aeration plants, various information is given, such as the period of aeration, and in air-operated plants the amount of free air required per unit of sewage; but as with the other systems, the relation of the size of the tank to the number of users is not mentioned. It is equally clear that there must be an

intimate relation, and as a matter of fact the relation is far more easily seen in an bio-aeration system than in the other systems. For the amount of sludge, that is solid matter, separated out is more easily measurable and provided extraneous matter is not admitted in undue quantity to the sewers, it is proportional to the number of users, for it is derived from them and from very little else.

The information available on the subject is very scanty. There are indications that the aerating tank capacity should be about 2 cubic ft. per user. Within what limits of dilution this will work is not determined, as there is no information available and published of a tank working on sewage stronger than 20 gallons per user, nor of one working on sewage weaker than 40 gallons per user. The former limit is probably about a 10 gallon sewage. The latter limit may be very high. For provided the action has time to reach the point at which the sludge will settle at all, it is only necessary to increase the size or the number of the settling hoppers until the period of quiescence is sufficient to separate the sludge and the liquid. Within these limits the strength of the sewage, that is the total liquid content, may vary enormously in the same tank in the same day without impairing its efficiency. It is for this reason that the bio-aeration processes are so admirably adapted to dealing with storm water. If the aeration tank capacity is rather liberal for the ordinary flow, and the settling tank capacity designed for the storm flow, a very large volume of liquid over and above the normal can be handled.

However flexible the main tanks may be for dealing with reasonable variations in flow, some storms will increase the flow to such an extent that additional provision must be made in the shape of storm tanks. The size of these is almost invariably given in terms of multiples of the daily dry weather flow. The reasons for this are purely empirical. The principles underlying the design and construction of storm tanks do not appear to be considered or at any rate discussed. The line of reasoning usually followed is that if a certain multiple of the daily dry weather flow—usually 3 or 4 times—is ponded up to be dealt with at leisure, the excess over this figure in a heavy storm will be so dilute that it can be neglected. This is usually true but not always, for sometimes a violent increase in the intensity of a storm may bring down all sorts of accumulated dirt not moved by the gentler flow, which was however sufficient to bring the storm tanks into action.

When a storm occurs, the flow of sewage in the sewers increases and frequently becomes very foul. This increased foulness is due partly to organic matter in solution, but chiefly to organic matter in suspension. As with average sewage, there are

three classes of matter to be considered: that which will float: that which will settle: and that which is in solution or so finely divided that it does not easily separate out either by flotation or settlement.

The floating matter is offensive to the eye; but otherwise it is probably not of serious importance as it is rapidly carried away. It is easily caught. The heavy matter which will settle is of serious importance for if left to itself, it may settle in situations in which it may give rise to serious nuisance and danger as it decomposes. It can be caught for treatment by suitable tanks. The finely divided matter which neither floats nor settles is the most difficult to deal with, but by the time the floating and settling matter have been extracted, it is unlikely that the quality or quantity will be such as to be troublesome, or dangerous when diluted with the rainfall run off from the country in general. The design of the storm tanks must therefore be such as to secure that the floating matter will be caught, and the settling matter brought down. When these two conditions are fulfilled, the determination of the quantity of liquid to be held must be made to suit local conditions.

The floating matter can be caught with ease by means of two hanging baffles like scum boards in a septic tank. The first should be deep, somewhat similar to the hanging baffle, separating the first compartment of the Clemesha Pattern tank from the second. The second, as found by experience, should extend 2′—0″ to 2′—6″ below water level. To bring down the settling matter the necessary conditions are similar to those in detritus tanks with this difference that the solids to be settled are much lighter: that is the cross sectional velocity must be reduced to such a point that it is insufficient to support in suspension the matter to be settled or to disturb the matter already settled and the length of time taken to pass through the tanks must be sufficient for the settling matter to come down, for in a continuous flow storm tank there is a forward movement all the time and the path of the settling matter will be a falling curve. It is not easy to determine without experiment on each particular sewage what the cross sectional velocity should be. Probably about 0.1 ft. per-sec. is the maximum, and 0.01 ft. per sec. is the minimum. Much will depend on what is done with the effluent from the storm tanks. If it flows into a running stream, the velocity through the storm tanks must be much less than the velocity of the stream, so that anything passing in suspension through the tanks will be kept in suspension by the velocity of the stream and carried right away. The velocity through the tanks should probably not exceed one-fiftieth of the velocity of the stream.

With a velocity of 0.1 ft. per sec. the cross sectional area required is about 20 sq. ft. per million gallons per day. The solids capable of settling with reasonable rapidity in most sewages will come down within a distance of 100 ft. When the cross sectional velocity is 0.1 ft. per sec., the time taken for the sewage to flow through a tank 100 ft. long will be 17 minutes. If the cross sectional velocity is 0.01 ft. per sec. the time taken will be nearly 3 hours. Some experiments on this subject were made by George A. Johnson and published in his report on Sewage Purification, Columbus, 1905. With a velocity of 0.01 ft. per sec. through a tank 8 ft. wide and 7 ft. deep, 35% of the suspended matter came down in the first 40 ft. of the tank, 50% in 120 ft., 57% in 160 ft. and only 60% in 200 ft. Where conditions are good and the outfall favourable 80 ft. length will be ample. In some places even less will be sufficient. In only very few places will it be worth while to give more than 100 ft. Steuernagel's sedimentation experiments at Cologne gave the following results: With cross sectional velocities of 0.01 ft. per sec. the removal of suspended matter was 72%: of 0.06 ft. per sec. 69%: and of 0.1 ft. per sec. 59%. It appears therefore that there is rarely any necessity to reduce the velocity below 0.1 ft. per sec. The first 50% can be brought down easily, and the other 50% is not usually worth troubling about unless there is reason to believe that the storm run-off will pick up poisonous matter in solution or in very fine suspension and then the whole problem may need tackling from the other end, for such poisonous liquids should probably never find their way into the sewers. Chemical agents would bring down much of the second 50% if that is really desirable; but the additional complication to the works is rarely worth while. As has been seen already, the problem is simplified in bio-aeration plants.

Consider these remarks side by side with the recommendations* of the Sewage Disposal Commission (Fifth Report):—"We find that the injury done to rivers by the discharge into them of large volumes of storm sewage chiefly arises from the excessive amount of suspended solids which such sewage contains, and that these solids can be very rapidly removed by settlement, we therefore recommend as a general rule:

"(1) That special stand-by tanks (two or more) should be provided at the works and kept empty for the purpose of receiving the excess of storm water which cannot properly be passed through the ordinary tanks. As regards the amount which may properly be passed through the ordinary tanks, our experience shows that in storm times the rate of flow through these tanks may usually be increased up to about three times the normal dry weather rate of flow without serious disadvantage."

The recommendation to keep the storm tanks empty is clearly due to the old idea that storm tanks are to pond up the worst of the flow until such time as it can be treated at leisure. The tanks will begin to perform their duty of settling out solids which the Commissioners recognise as the most important, immediately the first storm flow enters, if they are already full. Moreover if they are full of clean water, as they should be, they will help to purify the storm flow by dilution. If they are empty, the settling action is not only delayed until they are full, but for some little time later, as the incoming liquid keeps everything churned up until the tanks are full enough to form a cushion.

The extra quantity that can be allowed through ordinary septic tanks has already been shown to be eight times the dry weather flow for a five gallon sewage, and nil for a 10 gallon sewage.

"(2) That any overflow should only be made from these special tanks and that this overflow should be arranged so that it will not come into operation until the tanks are full."

This agrees entirely with everything suggested above, and is the inevitable logical conclusion.

"(3) That no special storm filters should be provided, but that the ordinary filters should be enlarged to the extent necessary to provide for the filtration of the whole of the sewage, which, according to the circumstances of the particular place, requires treatment by filters":

This again agrees with the arguments in this paper that in any sewerage system there will be a certain quantity of putrefactive matter to be oxidised and nitrified and a certain quantity of filtering media will be necessary for this purpose.

"In most cases it will probably suffice to provide stand by tanks capable of holding one quarter of the daily dry weather flow, and it will not be necessary to provide for filtering more than three times the normal dry weather flow."

No reasons are given for fixing the figure at one quarter of the dry weather flow. The Commissioners have been arguing that Local Government Board requirements of special storm filters for treating storm flow up to six times normal flow are too rigid. They have cut down the stand by equipment recommended, and appear not to have had the courage to go all the way.

Taking an illustration from actual figures we find that a storm tank for a flow of 1,000,000 gallons per day to give a cross sectional velocity of 0.01 ft. per sec. will require a cross section of 200 sq. ft.

To bring down some 60 per cent of the suspended solids the length will be 100 ft. The capacity therefore will be 125,000 gallons or one-eighth of the day's flow. If we are content with 50 per cent removal of the solids, a tank one-tenth the cross section, and only holding one-eightieth of the day's flow will suffice.

Precisely what should be done with the liquid effluent from storm tanks is not clear. If it can be turned loose in a relatively large body of water, no harm is likely to be done. But to return to first principles: the area served by the sewerage system contains a certain population who produce a certain quantity of waste putrefactive matter which has to be purified and rendered innocuous. The most important part of that waste matter consists of sewage proper, namely animal excreta, and of that the most important part is the human excreta. The remainder consists of excreta of other animals principally cattle and horses: of the liquid parts of kitchen refuse: and of bath water and street and other washings. In a disposal system designed to deal with the excreta of the population served, storm water entering the sewers will dilute the sewage and, provided the dilution is not in excess of the limits laid down, will not interfere with the action. But the storm water will inevitably bring in other matter which does not usually enter the sewers. This will enter as suspended solids, which will be extracted in the storm tanks. But in the sewers and in the tanks themselves, some part of the suspended matter such as rotting vegetation or the like will pass into solution, producing frequently a peculiarly offensive liquid. To pass such liquid through a special filter attached to the storm tanks, and only used when the storm tanks are in operation, will do no good, for there will not be enough live organisms in the bed to produce any appreciable effect. It follows that if the storm tank effluent must be filtered at all, (and in many places it certainly need not) the only place on which it can be done is in the ordinary filters. These therefore must be made of such a size as to give a rather better effluent than would otherwise be necessary in ordinary times, so that the effluent at storm times may be up to the standard required in the particular place. This standard need certainly not be so high as that required in ordinary times, for when a storm is heavy enough to bring the tanks into action, it will certainly provide a great deal of dilution water in the out-fall stream. If the filtration is sufficient to start the nitrifying action at such times, that is almost certainly all that is required.

The detailed design of the storm tanks must be made to suit the particular place. Almost any shape which gives the correct cross sectional velocity and correct distance of travel at that

velocity will answer equally well. When the size becomes considerable, a number of tanks in parallel so arranged that they come into operation successively as the flow increases will be found easier to keep in good working order than one large tank.

In conclusion to recapitulate the principles already discussed :—Speaking generally the purification of sewage consists in separating out the suspended solids, liquefying as much of them as is possible and oxidising and nitrifying the effluent liquid. The separation of the solids is usually dealt with in successive processes, the effluent from each process being oxidised and nitrified, separately. First the mineral grit is extracted by reducing velocity to such a point that it will settle, but as little else as possible will settle. This velocity should be from .75 to 1.25 ft. per sec. and the length of travel at that velocity from 30 to 50 ft. Secondly, the floating solids are held in a tank or in a chamber of a tank until they break down, and velocity is again reduced so that more suspended matter settles, and in many tanks time is given for the settled solids also to change. In a Clemesha tank dealing with any sewage from 5 to 40 gallons this chamber will have a capacity of about $\frac{1}{4}$ cu. ft. per user. Nearly all the systems are approximately similar to that point. Then divergence takes place. In a Clemesha tank the effluent of the first chamber, and a considerable quantity of the settled solids find their way together into the next compartment which has a capacity on a similar sewage of about $1\frac{3}{4}$ cu. ft. per user and in which the bulk of the remainder of the suspended solids is held either as a scum or as a sludge. The Clemesha tank effluent is much more easily filtered if it passes through a macerating tank to extract the remaining solids. The best size is not yet determined. Evidence points to gross tank capacity of 2 cu. ft. per user : the tank being filled with ballast of about two inch cubes. In the Jameson system at Pretoria, his Watson tank has a capacity of 1 cu. ft. per user. This clearly will take the bacterial action rather further than the first compartment of the Clemesha tank. The effluent from this tank goes straight to the filters and the sludge, which is removed regularly twice a day and while still quite fresh, is taken to sludge digestion tanks which are now being worked on a continuous flow principle. The sludge digestion tanks are again contrivances for the separation of solids and liquids and here the liquid is taken on to land, the best filter as long as it is not overloaded, and the sludge dried, and used as a fertiliser also in the land. The capacity of these tanks appears to be about 1.5 cu. ft. per user.

The various double storied tanks come midway between the Clemesha pattern tank which separates solid and liquid in the first

compartment and remixes them in the next and the Jameson system which separates them definitely and finally.

This complete separation at each stage appears to be the logical sequence. The detritus tanks take out the road grit, and let the sewage proper go forward. The Watson tank separates off liquid fit to go straight on the filters and sends sludge to digestion tanks which again separates solids and liquids, and sends the liquid to a filter, namely land and dries the sludge. When storm tanks come into action they again separate solids and liquids and send the liquid for oxidisation by filters or by dilution.

From end to end sewage disposal resolves itself into the separation of solids from liquids in successive processes, and the oxidisation of the liquid effluent from each process as soon as it is sufficiently clarified not to clog up the oxidising apparatus. A suitable arrangement of the successive processes will deliver liquid effluent to the filters in such a condition as to be easily oxidised, and reduce the solid residuum to an inoffensive minimum. Each separation process is principally mechanical and each oxidisation process principally bacteriological and chemical.

The Design of Sewage Disposal Works.

PLACE.	Population.	Water Supply: Gallons per day.	Water Supply: Per head.	Sewage: Gallons per day.	Sewage: Per head.	Detritus Tanks: Size.	Detritus Tanks: Cross Sectional Velocity ft per second.	Sedimentation Septic or Aeration Tanks: Size.	Sedimentation Septic or Aeration Tanks: C. ft. per user	Sedimentation Septic or Aeration Tanks: Period of rest hours.	Sedimentation Septic or Aeration Tanks: Sludge Capacity C. ft.	Storm-Tanks: Size.	Storm-Tanks: Cross Sectional Velocity ft. per second.
n District (Ill) Eng. News Records.) n. 31, 1924 ..	28260 (Present) 75000 (Future)	..	..	18600000 Gal.	250 88·3	..	..	Activated Sludge Imhoff Tanks ..	.. 2·25	6·5 3		..	..
ys and Tilbury Sewerage Scheme Surveyor. arch 7, 1924 ..	66,000 (36,000)	..	..	10000000	25	..	..	Settling Tank 4 of 400000 Gallons Capacity ..	..	..	..	2 of 20000 Gallons Capacity	..
coln Sewage sposal Plant ig. News Record pril 10, 1924 ..	Present 50,000 Future 80,000	..	..	4,000,000 6,500,000	80 81·2	..	..	Six Separating Tanks 27' x 27' x 14 with 45° Hopper Bottom ..	..	1·9	.	..	..
field Bio-Aeration Extension heme .. he Surveyor and Municipal and County Engineer July 4, 1924 ..	.. ..	.. ..	.. ..	15,000,000 Gallons D.W.F. ..	.. ..	.. ..	.	12 Units (269' x 130' x 4'-5' Each = 900,000 Gallons) Settling tanks 9 per unit Each 25'-3"x25'-3"x22'x6" =37,000 Gallons .	.	..	..	..	..

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS. Size.	FILTERS. C. ft per user	HUMUS TANK. Size.	HUMUS TANK. C. ft per user.	HUMUS TANK. C. ft. air per gal.	SLUDGE. Digestion Tank.	SLUDGE. C. ft. per user.	C. ft. air per gal. Sewage.	ANALYSIS. Suspended Solids.	ANALYSIS. Chlorine	ANALYSIS. Free Ammonia.	ANALYSIS. Albumen Ammonia	ANALYSIS. Nitrates Nitrites.	ANALYSIS. 4 Hours Oxygen.	REMARKS.
lgin District (Ill) (Eng. News Records.) Jan. 31, 1924 ..	.	14	..	..	..	.	..	1·25	29·6	.	..	..	2·9	14·9	Treatment works planned on the Base of 88·3 Gal. per head.
rays and Tilbury Sewerage Scheme Surveyor. .. March 7, 1924 ..	27×9000 C. ft	..	.	..	..	..	..	..	..	..	..	..	..	.	Purification works Based on 36000 population.
Lincoln Sewage Disposal Plant .. Eng. News Record April 10, 1924 .	4 Filter Beds =2·6 Acres Each 6 Deep	..	..	..	..	Six Tanks same as Separating Tanks	·78	.	.	..	.	..	..	..	16 Sludge Beds each 26′×125′×1′
heffield Bio-Aeration Extension Scheme The Surveyor and Municipal and county Engineer July 4, 1924 ..	..	..	.	..	..	..	..	..	.	..	.	..	..	7·38 ·98	(Sheffield Sewage after preliminary tanks.) Effluents.

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	Water Supply. Gallons per day.	Water Supply. Per head.	Sewage. Gallons per day.	Sewage. Per head	Detritus Tanks. Size.	Detritus Tanks. Cross Sectional Velocity ft. per second.	Sedimentation Septic or Aeration Tanks. Size.	Sedimentation Septic or Aeration Tanks. C. ft. per user.	Sedimentation Septic or Aeration Tanks. Period of rest hours.	Sedimentation Septic or Aeration Tanks. Sludge Capacity C. ft.	Storm-Tanks. Size.	Storm-Tanks. Cross Sectional Velocity ft. per second.
Engineering News Record 25-9-24 Springfield State Hospital ...	1500 (Actual) 2000	.	...	240000	120	...	..	Primary Settling Tanks (Imhoff) (Old Tanks Remodelled) Final Settling Tank	...	1½	...	...	...
Maryland House of Correction ...	625 (Actual 1000	...	...	200000	200	...	. .	Primary Settling Tanks Final ,, ,,	...	2 1½	...	...	...
Maryland Tuberculosis Sanatorium ...	600 (Actual) 1000	...	...	100000	100	...	..	Primary ,, ,, Final ,, ,,	...	2 1½	...	...	...
Crownsville State Hospital ...	600 (Actual) 1000	...	...	150000	150	...	..	Primary ,, ,, Final ,, ,,	...	1½ 1	...	...	...
Colored Tuberculosis Sanatorium	150	...	...	30000	200	...	...	Primary ,, ,,	...	1	...	...	...
Romford R.D.C. Essex ... Surveyor 10-10-24	150000	...	...	...	...	...	...	4 × 100′ × 30′ × 7½′ Sedimentation Tanks	...	...	...	...	...
Taunton Sewage Works ... Surveyor 10-10-24	29000 (Actual 24500)	...	...	3 × D.W.F. as Sewage 2250000 as Storm Water	77⅝ 91⅚ Actual	3 Nos. Total Capacity 1·38 - D.W.F. = 19413 Gal.	...	Aeration Tanks 2 Nos Capacity Total 376000 D.W.F. 500000 W.W.F Settling Tanks Total Capacity 6 Nos.—188550	...	...	...	Preliminary & Storm Water Settling tanks 2 Nos Capacity Total 1/3 D.W.F = 260000 (Dry Weather Flow) 1/2 D.W.F. = 380000 Wet Weather Flow	

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft. per user.	Size.	C ft. per user.	C. ft. air per gal.	Digestion Tank.	C. ft. per user.	C. ft. air per gal. Sewage.	Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
ngineering News Record 25-9-24 Springfield State Hospital	Trickling Filters 30 x 75''25 x 87''25 x 7 Intermittant Sand Filter.	...	...	0·18											
Maryland House of Correction ..	Trickling Filters 30 x 68''25x80''25x 6''75	...	...	·70 ·37											
Maryland Tuberculosis Sanatorium ..	Trickling Filters 12x45'x57'x6 Intermittant Sand Filter 4x26x42	...	..	1·0 ·54											
Crownsville State Hospital ..	Trickling Filters 12x58'x63'x5''5 Sand Filters 4x36'x75'	...	...	1·[illegible] ·875											
Colored Tuberculosis Sanatorium	...	...	...	2·5											
omford R. D. C. Essex ... Surveyor 10-10-24	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Two Tidal Storage Tanks 2 x 100' x 3' x 6'½ outfall sewer.
aunton Sewage Works .. Surveyor 10-10-24															

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY. Gallons per day.	WATER SUPPLY. Per head.	SEWAGE. Gallons per day.	SEWAGE. Per head.	DETRITUS TANKS. Size.	DETRITUS TANKS. Cross Sectional Velocity ft. per second.	SEDIMENTATION SEPTIC OR AERATION TANKS. Size.	SEDIMENTATION SEPTIC OR AERATION TANKS. C. ft. per user.	SEDIMENTATION SEPTIC OR AERATION TANKS. Period of rest hours.	SEDIMENTATION SEPTIC OR AERATION TANKS. Sludge Capacity C. ft.	STORM-TANKS. Size.	STORM-TANKS. Cross Sectional Velocity ft. per second.
Manchester:— Withington works Small Unit ...	...	...	...	357000	...	...	...	Aeration Tank 40000 Gal. Settlement Tank 27000 Gallons	...	4·0 1·8	...	...	...
Surveyor 24-10-24 Large Scale Unit	...	...	...	1490000	...	...	...	Aeration Tank 325000 Gal. Settlement Tank 88000 Gal.	...	5·2 1·2	...	...	...
Reading's New Activated Sludge Works ... Surveyor Feb. 27, 1925 ..	100000	...	...	3000000 D. W. F. 6000000 W. W. F.	30 60	3 Nos Each 14000 Gallons Capacity 40000 Gallons Each Municipal Engineering and Sanitary Record Feb. 26. 1925	...	Aeration Tanks 4 Nos. Each 436000 Gallons Capacity 108′ x 30′ 6″ x 22′ Connecting Tanks 3 Nos Each 63000 Gallons Capacity 30′ 6″ x 15′ x 22′ Settlement Tanks 2 Nos. each 225000 Gallons 50′ x 50′ x 2′ 6″ (Puri Model) Reaeration Tanks 2 Nos. each 131000 Gallons 54′ x 21′. 6″ x 20′	...	..	...	...	...
New York Sewage Disposal ... Water and Water Engineering 20-6-25 ...	20000	...	..	20 x 20000 & 100000 (Trade Waste)	20	...	...	Storm water settling tanks 4 D.W.F. Sewage treatment 5 pairs 18′ x 18′ Dortmund Tanks 6 Mud Reconditioning Chambers 8′ x 8′ 1 Mixing Chamber & 3 Aeration Chambers 13′ x 13′	...	...	...	...	...

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft. per user.	Size.	C. ft. per user.	C. ft. air per gal.	Digestion Tank.	C. ft. per user.	C. ft. air per gal. Sewage.	Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
lanchester:— Withington works Small Unit ... Surveyor 24-10-24	...	...	...	...	..		.	1·08	7·6 32	4·0 4·0	1·69 1·59	·50 ·095	... ·17	2·63 ·45	Screened & Detritus free sewage Effluent.
Large Scale Unit	...	...		. .	...		..	·87	7·8 ·62	... . .	1·38 1·34	·48 ·095	... ·17	2·25 ·43	Screened & Detritus free sewage. Effluent.
leading's New Activated Sludge Works ... Surveyor Feb. 27, 1925 ...	...	...	...	...		Sludge Disposal 19 beds of clinker. Total area 20000 super-yds.	...	..	..		.	..	.	.	6" Division through centre cross Baffle every 18' No Divn. or Baffles. Top 8' wall vertical Remainder 20'—6" Slope 60° 6" Division through centre 18' Baffles cross walls.
ew York Sewage Disposal ... Water and Water Engineering 20-6-25 ...	...	...	...	.	..			.	..	..	.	. .	..	...	Preliminary settlement in Nos. 1 & 2 pairs of Tanks the mud being extracted and dried on mud beds. It then flows to the rising chamber to receive a dose of activated mud mixture passes to No. 3 pair of Tanks and is finally settled Nos. 4 & 5.

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY. Gallons per day.	WATER SUPPLY. Per head.	SEWAGE. Gallons per day.	SEWAGE. Per head.	DETRITUS TANKS. Size.	DETRITUS TANKS. Cross Sectional Velocity ft. per second.	SEDIMENTATION SEPTIC OR AERATION TANKS. Size.	SEDIMENTATION SEPTIC OR AERATION TANKS. C. ft. per user.	SEDIMENTATION SEPTIC OR AERATION TANKS. Period of rest hours.	SEDIMENTATION SEPTIC OR AERATION TANKS. Sludge Capacity C. ft.	STORM-TANK. Size.	STORM-TANK. Cross Sectional Velocity ft. per second.
ochester Sewage Disposal 'aper:—Structural Conservation April, 1915.	400000	...	.	...	..	6 Nos. 90' × 10' × 3' (Effective Depth.)	...	10 units or 20 Tanks (Imhoff) Each tank = 110' × 35' × 40' Max. depth.	...	...	..	..	...
Ioldrege, Nebraski Sewage Disposal Engineering News Record. 8-10-25.	30000	...	...	300000	100	...	...	Two parallel flow Chambers	...	3	..	..	..
Wandle Valley Sur-ey Sewage Disposal Surveyor. 6-11-25	64000 (present) 96000 (future)	...	...	2400000 D W.F.	25	..	.	Settling Tanks capacity 2 millions ...	...	...	.	2 × 200' × 40' × 6' = 600000 gallons.	..

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS. Size.	FILTERS. C. ft. per user.	HUMUS TANK. Size.	HUMUS TANK. C. ft. per user.	HUMUS TANK. C. ft. air per gal.	SLUDGE. Digestion Tank.	SLUDGE. C ft. per user.	C. ft. air per gal. sewage.	ANALYSIS. Supended solids.	ANALYSIS. Chlorine.	ANALYSIS. Free Ammonia.	ANALYSIS. Albumen Ammonia.	ANALYSIS. Nitrates Nitrites.	ANALYSIS. 4 Hours Oxygen.	REMARKS.
Rochester Sewage Disposal Paper:—Structural Conservation April 1915.	...	..	...	...	...	*Sludge drying beds area : sq ft. per user 19' filtering material									
Holdrege, Nebraski Sewage Disposal Engineering News Record. 8-10-25.	Sprinkling filters	14·6	...	.	..	Sludge digestion capacity sludge bed area 1 sq. ft. per capita	2	..	...	...	...	...	...	...	Rect. final settling basin hopper bottom with 15 min. detention period.*
Wandle Valley Survey Disposal ... *Surveyor. 6-11-25	...	...	Primary 6x20'x20'x20' = 200000 Gal Secondary 2 31' dia. 40' deep = 200000 Gallons	.		...		...	...	...	...	...	...	..	Bacteria bed 6 (1 acre) 502'×91'×5'

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	Water Supply. Gal. per day.	Water Supply. Per head	Sewage. Gallons per day.	Sewage. Per head.	Detritus Tanks. Size.	Detritus Tanks. Cross Sectional Velocity ft. per second.	Sedimentation Septic or Aeration Tanks. Size.	Sedimentation Septic or Aeration Tanks. C. ft. per user.	Sedimentation Septic or Aeration Tanks. Period of rest hours.	Sedimentation Septic or Aeration Tanks. Sludge Capacity C. ft.	Storm-Tanks. Size.	Storm-Tanks. Cross Sectional Velocity ft. per second.
Sunninghill & Sunningdale Sewage Purification works (Berks) ... Journal of the Institute of Sanitary Engineers Sep. '25	6000		...	D. W. F.	30	2 No. of D. W. F. or 2625 Gallons (Based on 8500 population)		Settling Tanks 2 Nos. Capacity 100800 Gal. = 2 × 24′ × 24′ × 24′ lower half of conical shape.	...	..	..	2 Nos. Total capacity = 43132 gals.	..
Sewage disposal at Bentley with Arkseys Survèyor. 20-8-26.	22000	...	..	D. W. F.	29 Gals.	...	..	One Liquefying Tank capacity 45000 gallons three wet period Tanks 45000 gallons each.	...	...	..	..	...
Up to date Sewage Works, Hoscar Pemberton Installation ... Municipal Engineering, Sanitary Record & Municipal Motor. (May 26, 1927.)	120000	.	..	D. W. F. 3300000 Gallons.	28 Gals.		...	Settling Tank Preliminary settling Tank capacity 77500 gallons 3 more settling Tanks with total capacity 1146450 gallons total = 1223950 gallons.	10·2 per user	9½ hours	.	928000 gals. 1 Tank, 74′ dia. of 376250 gals. four others.	..

The Design of Sewage Disposai Works—contd.

PLACE.	FILTERS. Size.	FILTERS. C. ft. per user.	HUMUS TANK. Size.	HUMUS TANK. C. ft. per user.	HUMUS TANK. C. ft. air per gal.	LUDGE. Diges-tion Tank.	LUDGE. C. ft. per user.	C. ft. air per gal. sewage.	ANALYSIS. Suspended solids.	ANALYSIS. Cholorine.	ANALYSIS. Free Ammonia.	ANALYSIS. Albumen Ammo-nia.	ANALYSIS. Nitrates Nitrites.	ANALYSIS. 4 Hours Oxygen.	REMARKS.
Sunninghill & Sunningdale Sewage Purification works (Berks) ... Journal of the Institute of Sanitary Engineers Sep. '25	2 percolating filters each 9 × 1217 cu. ft	..	2 Nos. each 15000 Gal.												
Sewage disposal at Bentley with Arkseys Surveyor. 20-8-26.	Bacterial Filters 3 No. each 100' dia. and 6' deep. Sludge Filters 6 Nos														
Up-to-date Sewage Works, Boscar Pemberton Installation ... Municipal Engineering, Sanitary Record & Municipal Motor. (May 26, 1927.)	...		320000 Gal. 40' × 40' × 32½'												

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY.		SEWAGE.		DETRITUS TANKS.		SEDIMENTATION SEPTIC OR AERATION TANKS.				STORM-TANKS.	
		Gallons per day.	Per head.	Gallons per day.	Per head.	Size.	Cross Sectional Velocity ft. per second.	Size.	C. ft. per user.	Period of rest hours.	Sludge Capacity C. ft.	Size.	Cross Sectional Velocity ft. per second.
Design & construction of Trenton New Jersey Sewage Treatment Works ... Surveyor, 14-10-27	120000	...	...	17900000 Gallons.	148	...	...	3 batteries, 4 to a battery each Tank 114′ × 35′ × 31′	...	...	21452 or 1·70 per head		
Hertford Sewage Disposal Works By S. M. Senior, A.M.I.C.E. Borough & Water Works Engineer & Surveyor. (Journal of the Institution of Sanitary Engineers, December, 1928.)	10712 (1921) over 12000 (present)	...	...	1000000 Gallons (D. W. F. in 1923) Designed for 2000000 Gallons for full treatment.	$93\frac{1}{3}$ $83\frac{1}{3}$ present. $186\frac{2}{3}$ $166\frac{2}{3}$ present.								

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft.	Size.	C. ft. per use.	C. ft. air per gal	Digestion Tank.	C ft. per user.	C. ft. air per gal Sewage.	Suspended Solids.	Chlorine	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
Design & construction of Trenton New Jersey Sewage Treatment Works .. Surveyor, 14-10-27															
Hartford Sewage Disposal Works By S. M. Senior A.M I.C E. Borough & Water Works Engineer & Surveyor. (Journal of the Institution of Sanitary Engineers, December, 1928.)															

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY. Gallons per day.	WATER SUPPLY. Per head.	SEWAGE. Gallons per day.	SEWAGE. Per head.	DETRITUS TANKS. Size.	DETRITUS TANKS. Cross Sectional Velocity ft. per selection.	SEDIMENTATION SEPTIC OR AERATION TANKS. Size.	SEDIMENTATION SEPTIC OR AERATION TANKS. C. ft. per user.	SEDIMENTATION SEPTIC OR AERATION TANKS. Period of rest hours.	SEDIMENTATION SEPTIC OR AERATION TANKS. Sludge Capacity C. ft.	STORM-TANKS. Size.	STORM-TANKS. Cross Sectional Velocity ft. per second.
Sewage Disposal Plant Pontywal Talgarth Engineering. July, 21, 1916. P. 56	400 persons	...	...	16000 Gallons	40	...	...	Sedimentation & septic tanks.	5·4 c. ft. per head =34 galls.	3 days	...	...	...
Sewage Disposal Mont Grentus Sewage Plant Engineering Record Oct. 3, 1914. P. 388	..	...	...	...	...	...	...	Imhoff Tanks & percolating filters.	...	7 to 8 hours	...	...	...

The Design of Sewage Disposal Works—concld.

PLACE.	FILTERS. Size.	FILTERS. C. ft. per user.	HUMUS TANK. Size.	HUMUS TANK. C. ft. per user.	HUMUS TANK. C. ft. air per gal.	SLUDGE. Digestion Tank.	SLUDGE. C. ft. per user.	C. ft. air per gal. Sewage.	ANALYSIS. Suspended Solids.	ANALYSIS. Chlorine.	ANALYSIS. Free Ammonia.	ANALYSIS. Albumen Ammonia.	ANALYSIS. Nitrates Nitrites.	ANALYSIS. 4 Hours Oxygen.	REMARKS.
Sewage Disposal Plant Pontywal Talgarth Engineering. July, 21, 1916, P. 56	Primary Filter.	9.66 cu. ft. per head	1st Humus Chamber.	·624 cu. ft. per head	...	...	...	...	...	...	...	...	...	...	Distributors revolving arms worked by tippers open channels with serrated edges.
	Secondary Filter.	15·78 cu. ft. per head	2nd Humus Chamber.	0·31 cu. ft. per head											
Sewage Disposal Mont Grentua Sewage Plant Engineering Record Oct. 3, 1914, P. 388	Slag Filter 1300000 per acre per day.	...	...	...	...	...	...	...	...	...	...	...	...	..	Draw off 3′ below surface.

The Design of Sewage Disposal Works.

PLACE.	Population.	Water Supply: Gallons per day	Water Supply: Per head	Sewage: Gallons per day	Sewage: Per head	Detritus Tanks: Size.	Detritus Tanks: Cross Sectional Velocity ft per second	Sedimentation Septic or Aeration Tanks: Size	C ft per user	Period of rest hours	Sludge Capacity C ft	Storm-Tanks: Size.	Storm-Tanks: Cross Sectional Velocity ft. per second.
Crewe													
Surveyor 2-3-23 ..	..	..	..	..	..	3×25'×25'×6'	..	..	..	..	..	2×120'×60' ×3'-5" 50400 & one unit 75600	·04 to ·09
Present ..	47,210	708 150	15	1,000 000	21	One used at a time	01	4x125x150'x7 5'=187500	4	28	..		
Future ..	..	..	.	1,500,000	32		02	Open septic tanks	..	19	..		
Eldorado Kansas Eng. News Record 21-6-23 ..	2705	.	..	..	...	..		2×18×58×8'=16704	6				
	16246	..	..	..	..	..	..	Septic tanks	1				
	10995	..	..	..	..	..	..	Changed one tank to activated sludge 18'×58'×15'=17600	1 6	..	..	..	..
Cleveland, Ohio Eng. News Record 19-8-20													
Westerly ..	311000	..	..	Dry 36000000 Wet 159000000	125	?×60'×7'×4'-2"	1	Two storied septic tanks	3 4	Tanks 4·4 Liquid 2 1	Scum ·6 per user sludge 1·2 per user.		
Easterly ..	575300	..	..	Dry 92000000 Wet 1055000000	160	Described as	·2	32×50'×25'×27'=1070000	..				
Southerly ..	222600	.	..	Dry 22000000 Wet 131000000	110	.	5 10	..	..				
Miami Camps Eng. News Record 19-8-20 .	500	..	.	.	.	..	. .	About 960	1·92				

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft. per user.	Size.	C. ft. per user.	C. ft. air per gal.	Digestion Tank.	C. ft. per user.		Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
Crewe Surveyor 2-3-23 ..	12 × 100′ dia. × 6′ =565488														
Present ..		11·5	3x95′x30′x5′ =42750	1	..	..	..	..	..	..	..	..	..	..	Quantity of Sewage said to be much more than Water Supply.
Future ..	and one unit 612612 ..	12·9	..	..	..										
Eldorada Kansas Eng. News Record 21-6-23 ..	..	..	..	..	1·25										
Cleveland, Ohio Eng. News Record 19-8-20. Westerly ..															
Easterly ..															
Southerly ..															
Miami Camps Eng. News Record 19-8-20 ..															

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY. Gallons per day.	WATER SUPPLY. Per head.	SEWAGE. Gallons per day.	SEWAGE. Per head.	DETRITUS TANKS. Size.	DETRITUS TANKS. Cross Sectional Velocity ft. per second.	SEDIMENTATION SEPTIC OR AERATION TANKS. Size.	SEDIMENTATION SEPTIC OR AERATION TANKS. C. ft. per user.	SEDIMENTATION SEPTIC OR AERATION TANKS. Period of rest hours.	SEDIMENTATION SEPTIC OR AERATION TANKS. Sludge Capacity C. ft.	STORM-TANKS. Size.	STORM-TANKS. Cross Sectional Velocity ft. per second.
Des-Plaines River Eng. News Record 9-12-20 ..	46200	..	..	4 to 10 Cusecs D. W. F. 2,160000 5,400000	46 ..	2×47′×3′×3·5′ ..	·19 ·47	Activated Sludge 126′x15′x21′=39690 3x126′x10′x30′=113400 153090	3·3	10·6			
Calumet Chicago Eng. News Record 9-6-21 ..	150000	..	..	30,780.000	205	..	..	Imhoff Tanks 30×103′×34′×20′= 2,101,200 Activated 2×103′×34′×14½′= 101558 2202758	14·7	10·7	2·3 per user	...	..
Houston Tex. Municipal Eng. & Sanitary Record 26-7-23 ..	138276	..	..	10.000,000	72½								
Canterbury Municipal Eng. & Sanitary Record 21-8-19 ..	24626	..	..	768000	31	..	..	Sedimentation size not given	..	..	..	..	..
Milwaukee Surveyor 9-7-20 1922 1930 1950	.. .. ..	.. .. ..	.. .. ..	65000000 85000000 129000000	.. .. ..	.. .. ..	·64 to 1·00	x340′×22′×15′ deep	..	6	..	..	..

The Design of Sewage Disposal Works—*contd.*

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS
	Size.	C. ft. per user.	Size.	C. ft. per user.	C. ft. air per gal.	Digestion Tank.	C. ft. per user.		Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
Des-Plaines River Eng. News Record 9-12-20 ..															
Calumet Chicago Eng. News Record 9-6-21 ..	130 × 248½ × 6 = 193830 Said to work from Imhoff Tank.	38	..	..	..	..	..		..	..	..	..	..	..	Details of Tanks cannot be reconciled with summary figures. Period of rest said to be 2·9′ hrs. Imhoff Tanks & 4 hrs. in Aeration Tanks.
Houston Tex. Municipal Eng. & Sanitary Record 26-7-23 ..															
Canterbury Municipal Eng. & Sanitary Record 21-8-19 ..	11 × 80′ Dia. × 5′-6″ = 27646 C. ft. × 11 = 304106	12	..	..	..	..	..		5·19	10	0·102	0·112	4·61	0·83	Effluent analysis.
Milwaukee Surveyor 9-7-20 1922 1930 1950	..	..	..	..	..	..	..	Crude Tanked	28·5 ..	..	1·36	..	0·79	3·0	

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	Water Supply.		Sewage.		Detritus Tanks.		Sedimentation Septic or Aeration Tanks.				Storm-Tanks.	
		Gallons per day.	Per head.	Gallons per day.	Per head.	Size.	Cross Sectional Velocity ft. per second.	Size.	C. ft. per user.	Period of rest hours.	Sludge Capacity C. ft.	Size.	Cross Sectional Velocity ft. per second.
Pretoria Surveyor 9-3-23 ..	40,000	..	..	1,500,000	37	27′×6′×4″	1·5	4×9000 C. ft. deep	1	4	..	..	..
Cape Town Southern Suburbs Paper before Inst. C. E. ..	Present 81,355 Ultimate 290,000	..	..	..	25	..	..	..	..	18	6 months	¼ of D.W.F. 79′ dia. 5′ deep	..
Worcester Mass Eng. News Record 22-11-23 ..	243,000	..	..	28,000,000	156½	..	..	12×32040=384480 Sedimentation 12×70200=842400 Sludge TOTAL 1226880	5	2¼ 4½ 6¼ avr.	842400 C. ft. 34 C. ft. per user ..	..	..
Colombo Mr. R. E. Tickelt's Paper. 1st Instalment ..	60,000	..	..	1,500,000									
Northern ..	300,000	..	..	..	25	13,608 C. ft. Grit Chamber	·005	120960 C. ft.	2	12			
2nd Instalment Southern ..	65,000	..	..	600,000	25 25	5,400 C. ft. 2,240 C. ft.	.. ..	42960 59′x26′x ? 2 No. 13400	2 ..	12 3	..	..	..

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS. Size.	FILTERS. C. ft. per user.	HUMUS TANK. Size.	HUMUS TANK. C. ft. per user.	HUMUS TANK. C. ft. air per gal.	SLUDGE. Digestion Tank.	SLUDGE. C. ft. per user.		ANALYSIS. Suspended Solids.	ANALYSIS. Chlorine.	ANALYSIS. Free Ammonia.	ANALYSIS. Albumen Ammonia.	ANALYSIS. Nitrates Nitrites.	ANALYSIS. 4 Hours Oxygen.	REMARKS.
Pretoria Surveyor 9-3-23 ..	16×560 sq. yds. ×6′ deep =483840 C. ft.	12	..	..	..	4×15000 C. ft. =60,000 C. ft.	1·5	Crude: Crude	22·5	20·8	36·8	8·4	..	47·4	
								Crude: Crude in sewer	77	9·6	16·8	3·4	..	18·0	
								Crude: Mixed in the pail	28	5·6	3·0	1·0	..	6·13	
								Treated: Tank Liquor	14·2	5·3	3·25	0·88	..	5·1	
								Treated: Filter-effluent	2·6	5·9	1·80	0·30	2·20	1·40	
Cape Town Southern Suburbs Paper before Inst. C. E. ..	2¾ acres														
Worcester Mass. Eng. News Record 22-11-23 ..	14 acres ×10 ft. =435600×14	25													
Colombo Mr. R. E. Tickelt's Paper. 1st Instalment .. Northern .. 2nd Instalment Southern ..	428,400 C. ft.	7													

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY.		SEWAGE.		DETRITUS TANKS.		SEDIMENTATION SEPTIC OR AERATION TANKS.				STORM-TANKS.	
		Gallons per day.	Per head.	Gallons per day.	Per head.	Size.	Cross Sectional Velocity ft. per second.	Size.	C. ft. per user.	Period of rest hours.	Sludge Capacity C. ft	Size.	Cross Sectional Velocity ft. per second.
Colombo Mr. M. R. Atkin's Paper													
Two Storied Sedimentation Tanks A	..	..	..	..	..	..	..	7700 C. Ft.	..	4·5	..	..	..
B	..	..	..	..	..	..	..	12950 C. Ft.	..	3·0		..	..
C	..	..	..	..	..	..	..	31500 C. Ft.	..	8·0	..	..	
D	..	..	..	..	..	..	..	19750 C. Ft.	..	2·75	..	..	..
E	..	..	..	..	..	..	..	19450 C. Ft.	..	3·0	..	..	..
Sheffield Mr. Howarth's Paddle Wheel Mechanical Agitation System.	1,000,000 actual 500,000 to 600,000	..	..	..	..	..	..	354,400 Gallons 201′-5″×75′-10½″×4′ =61,155 C. Ft.	..	6·8	..	..	..
Hoyland Nether Surveyor 17-3-22..	11,000	..	..	139,000	12½	2 Nos. of 776 C. ft. Total Capacity	..	22,464	2	22·3	..	..	..
Kershaw's Book													
Caterham Barracks. (Crude Sewage very strong.)	..	..	..	..	..	..	..	..	..	..	..	..	..

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft per user.	Size.	C. ft. per user.	C. ft. air per gal.	Diges-tion Tank.	C. ft. per user.		Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammo-nia.	Nitrates Nitrites.	4 Hours Oxygen.	
Colombo Mr. M. R. Atkin's Paper.								Crude Sewage	23·0	8·7	2 8	2·4	..	6·0	
								Effluent Tank A	6·1	8·8	2 0	0 9	..	2·7	
Two Storied A	..	..	..	..	..	.	..	..	..	..	..	.	..	..	
Sedimentation B	.	..	..	..	..	..	..	..	..	..	..	..	..	..	
Tanks C	.	..	..	..	.	..	..	..	.		.		..	..	
D	.	..	..	..	..	..	..	Effluent Tank D	6·0	8 3	2·5	1 0		2·9	
E	..	..	.		..	..	..	Effluent Tank E	5·6	8·6	2·2	0·8	..	2·9	
Sheffield Mr. Howarth's Paddle Wheel Mechanical Agitation System.	..	..	..	..	..	..	..	Finsby { Crude	27·23	..	3·38	·62	..	5·40	
								Finsby { Effluent	3·0	..	3·30	·14	·16	·76	
								Sheffield. { Crude	77·42	.	5 09	1 22	..	13·93	
								Sheffield. { Effluent	3·0	..	4 41	0·19	·10	1·39	
Heyland Nether Surveyor 17-3-22..	2×30×30 3 1416×6 =33930 2×180×37×6 =79920 (or 109432 C. ft) 113850 C ft effect	10	..	..	..	..	..	Crude ..	84·80	..	7·12	1·27	..	15·41	
Kershaw's Book Caterham Barracks. { Crude Sewage very strong.	..	..	..	..	..	..	..	..	42·1	13·57	13·41	1·75	..	17·99	Not so strong as Pretoria.

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY. Gallons per day.	WATER SUPPLY. per head	SEWAGE. Gallons per day.	SEWAGE. per head.	DETRITUS TANKS. Size.	DETRITUS TANKS. Cross Sectional, Velocity ft. per second.	SEDIMENTATION SEPTIC OR AERATION TANKS. Size.	SEDIMENTATION SEPTIC OR AERATION TANKS. C. ft. per user.	SEDIMENTATION SEPTIC OR AERATION TANKS. Period of rest hours.	SEDIMENTATION SEPTIC OR AERATION TANKS. Sludge Capacity C. ft.	STORM-TANKS. Size.	STORM-TANKS. Cross Sectional Velocity ft. per second.
Little Drayton													
Strong ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Oswestry													
Average ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Exeter St. Leonards													
Weak ...	...	...	...	...	...	...	...	...	...	...	...	...	...
American Boston	...	...	...	...	...	...	...	...	...	...	...	...	...
Columbus ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Waterbway ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Gloversville ...	..	...	...	...	...	...	...	...	...	...	...	...	...
Worcester ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Chicago ...	...	...	...	...	...	...	...	...	...	...	..	...	...
Leeds Crude	...	...	...	...	...	...	...	...	...	...	...	...	...
1½ hours Septic Tank	...	...	...	..	...	...	...	...	...	...	...	...	...
24 hours Septic Tank	...	...	...	...	...	...	...	...	...	...	...	...	...
48 hours Septic Tank	...	...	...	...	...	...	...	...	...	...	...	...	...
72 hours Septic Tank	...	...	...	...	...	...	...	...	...	...	...	...	...

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft. per user.	Size.	C. ft. per user.	C. ft. air per gal.	Digestion. Tank.	C. ft. per user.		Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
Little Drayton Strong ...	...	...	...	...	...	...	...	...	23·9	11·40	7·57	1·41	0·00	24·44	
Oswestry Average ...	...	...	...	...	...	...	...	...	29·4	9·16	3·53	0·91	Trace	11·27	
Exeter St. Leonards Weak ...	...	...	...	...	...	...	...	...	26·7	6·58	2·49	0·55	...	6·53	
American Boston	...	...	...	...	...	...	...	...	13·5	...	1·14	·91	·004	5·6	
Columbus ...	...	...	...	...	...	...	...	...	20·9	6·5	1·10	·90	·029	5·1	
Waterbway ...	...	...	...	...	...	...	...	...	16·5	4·8	·78	1·48	·166	4·6	
Gloversville ...	...	...	...	...	...	...	...	...	40·6	15·8	1·20	2·30	·126	9·5	
Worcester ...		...	...	...	...	...	...	...	25·8	5·7	2·22	...	...	11·7	
Chicago ...	...	...	...	...	...	...	...	...	14·1	4·0	·88	·76	·46	3·8	
Leeds Crude	...	...	...	...	...	...	...	...	87·7	...	...	...	...	...	
1½ hours Septic Tank	...	...	...	...	...	...	...	...	19·2	...	1·56	0·54	...	5·21	
24 hours Septic Tank	...	...	...	...	...	...	...	...	11·4	...	1·51	0·45	...	4·84	
48 hours Septic Tank	...	...	...	...	...	...	...		10·9	...	1·62	0·38	...	4·30	
72 hours Septic Tank	...	...	...	...	...	...	...	...	9·9	...	1·79	0·34	...	3·59	

The Design of Sewage Disposal Works—*contd.*

PLACE.	Population.	WATER SUPPLY. Gallons per day.	WATER SUPPLY. Per head.	SEWAGE. Gallons per day.	SEWAGE. Per head.	DETRITUS TANKS. Size.	DETRITUS TANKS. Cross Sectional Velocity ft. per second.	SEDIMENTATION SEPTIC OR AERATION TANKS. Size.	SEDIMENTATION SEPTIC OR AERATION TANKS. C. ft. per user.	SEDIMENTATION SEPTIC OR AERATION TANKS. Period of rest hours.	SEDIMENTATION SEPTIC OR AERATION TANKS. Sludge Capacity C. ft.	STORM-TANKS Size.	STORM-TANKS Cross Sectional Velocity ft. per second.
Calcutta Experimental Station—													
Crude average ...	620,000	42 milln.	68	...	...	...	...	...	3·6	8	...	...	...
Crude maximum strength ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Compared with Manchester { Crude ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Compared with Manchester { Tank Effluent ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Calcutta Experimental— Research Report I.													
Crude average...	...	...	...	...	...	...	...	...	...	...	...	...	...
Course Filter ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Fine Filter ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Septic Tank ...	...	...	...	...	...	...	...	...	...	...	...	...	...
St. & Filter ...	...	...	...	...	...	...	...	...	...	...	...	...	...

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft. per user.	Size.	C. ft. per user.	C. ft. air per gal.	Digestion. Tank.	C. ft. per user.		Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
Calcutta Experimental Station—															
Crude Average ...	...	...	...	...	...	..	...	...	54·9	36·6	2·14	0·93	...	6·28	
Crude maximum strength ...	...	...	...	...	...	...	...	...	86·1	23·1	3·16	1·79	...	10·09	
Compared with Manchester. Crude ...	...	...	...	...	...	...	...	...	...	14·1	2·05	0·49	...	7·96	
Compared with Manchester. Tank Effluent...	...	...	...	...	...	...	...	...	...	10·3	1·54	0·23	...	5.25	
Calcutta Experimental															
Research Report I															
Crude Average ...	...	...	...	...	...	...	...	...	63	24·4	...	...	...	9·78	
Course Filter ...	...	...	...	...	...	...	...	...	21	24·8	2·01	1·13	0·14	5·90	
Fine Filter ...	...	...	...	...	...	...	...	...	15	24·0	1·75	1·41	0·07	4·20	
Septic Tank ...	...	...	...	...	...	...	...	...	16	41·3	2·74	0·50	..	3·37	
St. & Filter ...	...	...	..	...	...	...	...	...	4·7	40·3	1·99	0·40	0·45	2·21	

The Design of Sewage Disposal Works—*contd.*

PLACE.	Population.	WATER SUPPLY.		SEWAGE.		DETRITUS TANKS.		SEDIMENTATION SEPTIC OR AERATION TANKS.				STORM-TANKS.	
		Gallons per day.	Per head.	Gallons per day.	Per head.	Size.	Cross Sectional Velocity ft. per second.	Size.	C. ft. per user.	Period of rest hours.	Sludge Capacity C. ft.	Size.	Cross Sectional Velocity ft. per second.
Calcutta Experimental—*contd.*													
Research Report IV													
Average Crude Sewage Cold Weather ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Septic Tank 4 hours rest ...	...	...	...	..	...	..	...	...	1·8	4	...	...	...
Average Crude Sewage Hot Weather ...	...	...	...	...	...	..	...	...	...	...	...	...	...
Septic Tank 12 hours ...	...	...	...	...	...	...	...	...	5·4	12	...	...	...
Patna General Hospital	Average of 10												
1st Tank ...	320	3200 Gal.	10	...	...	...	...	480 C. ft.	1·5	22	...	...	...
2nd Tank ...	...	...	...	...	...	...	...	471 C. ft.	1·5	22	...	...	...
Effluent of Tank	...	...	...	...	...	...	...	...	...	...	...	...	...
Filter Effluent...	...	..	...	...	...	...	...	...	...	...	...	...	...
Patna Police Lines													
Septic Tank ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Effluent Pipe ...	...	...	...	...	...	...	...	..	...	...	...	...	...
Filter Effluent ...	...	...	...	...	...	...	...	...	...	...	...	...	...

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS. Size.	FILTERS. C. ft. per user.	HUMUS TANK. Size.	HUMUS TANK. C. ft. per user.	HUMUS TANK. C. ft. air per gal.	SLUDGE. Digestion Tank.	SLUDGE. C. ft. per user.		ANALYSIS. Suspended Solids.	ANALYSIS. Chlorine.	ANALYSIS. Free Ammonia.	ANALYSIS. Albumen Ammonia.	ANALYSIS. Nitrates Nitrites.	ANALYSIS. 4 Hours Oxygen.	REMARKS.
Calcutta Experimental—*contd.*															
Research Report IV															
Average Crude Sewage Sold Weather ...	...	...	...	...	...	...	...	...	53·0	9·3	1·62	0·87	...	5·83	
Septic Tank 4 hours rest ...	...	...	...	...	...	...	...	...	5·7	10·4	2·11	0·40	...	2·52	
Average Crude Sewage Hot Weather ...	...	...	...	...	...	...	...	...	53	9·3	1·62	0·87	...	5·83	
Septic Tank 12 hours ...	...	..	...	...	...	...	...	..	11·86	50·7	2 26	0·38	...	2·95	
Patna General Hospital															
1st Tank ...	...	...	...	...	...	...	—	...	9·6	8·1	2·53	0·33	0·118	2·49	Purely Domestic Sewage. Successive Stages on the same Sewage.
2nd Tank ...	...	...	...	...	...	...	...	...	8·8	8·2	2·46	0·33	0·112	2·25	
Effluent of Tank	...	...	...	...	...	...	...	...	7·6	9 0	2·37	0·35	0·237	1·93	
Filter Effluent ...	...	...	...	...	...	...	...	...	4·3	8·2	0 90	0·30	0·95	1·74	
Patna Police Lines															
Septic Tank ...	...	...	...	...	...	...	...	...	6·22	8·4	2·92	0·58	0·04	3·11	A Septic Tank Latrine. Successive stages on the same Sewage.
Effluent Pipe ..	...	...	...	...	...	...	...	...	6·82	8·9	2·38	0·24	0·05	2·73	
Filter Effluent ..	...	...	...	...	...	...	...	...	5·9	8·9	1·06	0·33	0·92	2·03	

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY. Gallons per day.	WATER SUPPLY. Per head.	SEWAGE. Gallons per day.	SEWAGE. Per head.	DETRITUS TANKS. Size.	DETRITUS TANKS. Cross Sectional Velocity ft. per second.	SEDIMENTATION SEPTIC OR AERATION TANKS. Size.	SEDIMENTATION SEPTIC OR AERATION TANKS. C. ft. per user.	SEDIMENTATION SEPTIC OR AERATION TANKS. Period of rest hours.	SEDIMENTATION SEPTIC OR AERATION TANKS. Sludge Capacity C. ft.	STORM-TANKS. Size.	STORM-TANKS. Cross Sectional Velocity ft. per second.
Patna Govt. House													
Ceptic Tank 1st Chamber	...	...	...	...	...	...	...	...	...	...	...	...	...
2nd Chamber	...	...	...	...	...	...	...	...	...	...	...	...	...
3rd Chamber	...	...	...	...	...	...	...	...	...	...	...	...	...
Macerator	...	...	...	...	...	...	...	...	...	...	...	...	...
Filter	...	...	...	...	...	...	...	...	...	...	...	...	...
Patna Experimental													
A. Tank													
Lower Chamber	70	2100 gal.	30		...	...		134 C. Ft.	1·9	10	...	...	...
Upper Chamber	...	...	...	...	...	...		...	...	...	...	...	...
Hydrolysing ...	...	...	...	...	...	...		...	...	...	...	...	...
B. Tank ...	62	1700 gal.	28	...	...	...		139 C. Ft.	2·2	19	...	...	...
C. Tank ...	49	2000 gal.	40	...	...	...	...	139 C. Ft.	2·8	10	...	...	...
Macerator ...	...	...	...	...	...	...	...	...	...	...	8 C. Ft.	...	...
D. Tank ...	51	2000 gal.	40	...	...	...	...	129 C. Ft.	2·5	9	...	...	...
E. Tank ...	108	1800 gal.	16	...	...	...	...	176 C. Ft.	1·6	6	...	...	...
Macerator ...	...	...	...	...		...	...		...		8 C. Ft.	...	...
Combined Tank Effluent	340	9600 gal.	28	...	...	...	...	717 C. Ft.	2·1	11	...	...	...
Brushwood Filter Effluent ...	...	...	...	...	...	...	...		...	...	...	...	...

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft. per user.	Size.	C. ft. per user.	C. ft. air per gal.	Digestion Tank.	C. ft. per user.		Suspended Solids	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
Patna Govt. House															
Septic Tank 1st Chamber									11 0	10 3	0·96	0·64	0·11	5·57	A purely domestic sewage. Successive stages on the same sewage.
2nd Chamber									14·8	11 0	1·12	0·37	0·09	6·73	
3rd Chamber									15·5	10·3	1·12	0·31	0·08	5·43	
Maceator ...									6·7	8·7	0·85	0·08	0·07	2·83	
Filter ...									6·43	8 9	0·23	0·11	0·99	2·81	
Patna Experimental															
A. Tank															
Lower Chamber									5 0	8·7	0·91	0·24	0·18	3·2	
Upper Chamber									12·1	9·0	1·39	0·14	0·06	4·7	
Hydrolysing ...									11·5	8·7	1·65	0·12	0·07	4·43	
B. Tank ...									7·6	9·3	1·39	0·16	0·08	3·0	
C. Tank ...									8·2	9·3	1·7	0 11	0·20	3·13	
Macerator ...									7·7	10·0	1·12	0 11	0·06	3·03	
D. Tank ...									7·3	8·3	0·93	0·21	0·08	2·23	
E. Tank ...									5·6	9·3	1·39	0·12	0·07	3·5	
Macerator ...									4·7	9·3	0·99	0 14	0·08	2·87	
Combined Tank Effluent ...									10·8	7·3	0·91	0·07	0·14	2·67	The Brushwood appears to have been disintegrating.
Brushwood Filter Effluent ...									24·5	6·8	0·64	0·96	0·80	2·4	

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	WATER SUPPLY.		SEWAGE.		DETRITUS TANK.		SEDIMENTATION SEPTIC OR AERATION TANKS.				STORM-TANKS.	
		Gallons per day.	Per head.	Gallons per day.	Per head.	Size.	Cross Sectional Velocity ft. per second.	Size.	C. ft. user.	Period of rest hours.	Sludge Capacity C. ft.	Size.	Cross Sectional Velocity ft. per second.
Gleme Sha's Book Shamnagar													
Grit Chamber ...	...	...	7½	...	...	...	...	...	...	...	...	...	...
Effluent ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Crude ...	...	...	...	...	...	...	...	...	...	...	...	...	...
Average samples { Crude ...	...	...	6	...	...	...	...	...	...	...	...	...	...
Average samples { Effluent ...	...	...	6	...	...	...	...	...	...	...	...	...	...
Model contact Beds	...	...	5	...	...	...	.	...	...	...	...	...	9
American Sewerage Practice Averages													
Large American Cities ...	...	...	178	...	...	...	...	...	...	...	...	...	...
American Mfg. Cities	...	...	95	...	...	...	...	...	...	...	...	...	...
Small American Mfg. Cities ...	...	...	69	...	...	...	...	...	...	...	...	...	...
American Residential & Rural ...	...	...	80	...	...	...	...	...	...	...	...	...	...
Large English Mfg. Cities ...	...	...	49	...	...	...	...	...	...	...	...	...	...
German Communities Emscher Dist.	...	...	...	...	...	...	...	...	...	...	...	...	...

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS.		HUMUS TANK.			SLUDGE.			ANALYSIS.						REMARKS.
	Size.	C. ft. per user.	Size.	C. ft. per user.	C. ft. air per gal.	Digestion Tank.	C. ft. per user.		Suspended Solids.	Chlorine.	Free Ammonia.	Albumen Ammonia.	Nitrates Nitrites.	4 Hours Oxygen.	
Cieme Sha's Book Shamnagar															
Grit Chamber ...	...	...	...	...	...	...	...	...	...	3·82	3·52	0·78	...	4·12	
Effluent ...	...	...	...	...	...	...	...	...	...	3·85	4·10	0·63	...	3·36	
Crude ...	...	...	...	...	...	...	...	...	...	4·0	...	4·5	...	16·0	
Average samples { Crude ...	...	...	...	...	...	...	...	...	...	6	...	2·0	5·2	2·4	
Average samples { Effluent...	...	...	...	...	...	...	...	...	...	6	...	7·82	0·59	4·54	
Model contact Beds															
American Sewerage Practice Averages															
Large American Cities ...	...	...	...	...	...	...	...	...	30·3	4·8	1·06	0·70	0·06	5·9	
American Mfg. Cities	...	...	...	...	...	...	...	...	45·0	10·9	2·65	1·19	0·14	13·3	
Small American Mfg. Cities ...	...	...	...	...	...	...	...	...	24·2	8·3	3·89	1·13	...	10·7	
American Residential & Rural ...	...	...	...	...	...	...	...	...	34·2	4·7	2·72	0·78	...	7·1	
Large English Mfg. Cities ...	...	...	...	...	...	...	...	...	66·8	16·2	3·65	1·48	...	26·6	
German Communities Emscher Dist.	...	...	...	...	...	...	...	...	...	20·9	3·37	...	...	...	

The Design of Sewage Disposal Works—contd.

PLACE.	Population.	Water Supply. Gallons per day.	Water Supply. Per head.	Sewage. Gallons per day.	Sewage. Per head.	Detritus Tanks. Size.	Detritus Tanks. Cross Sectional Velocity ft. per second.	Sedimentation Septic or Aeration Tanks. Size.	Sedimentation Septic or Aeration Tanks. C. ft. per user.	Sedimentation Septic or Aeration Tanks. Period of rest hours.	Sedimentation Septic or Aeration Tanks. Sludge Capacity C. ft.	Storm-Tanks. Size.	Storm-Tanks. Cross Sectional Velocity ft. per second.
Manchester Rivers Dept. Report 1914 Withington.	81,000	...	...	3675000	45	2 Nos. not said whether each or total 83400 galls.	...	Sedimentation 2 Nos. not said whether each or total 781000 gals. Emscher 200,000 gals. for 750000 gals. flow.	..	2			
Davyhulme ...	...	..	..	33897000	55		..	Sedimentation 4×300×100'×6'=1125000 gal. ea. total 45000000 galls. for 10412000 flow.	...	10·4			
				23485000	...	...	...	Septic Tanks 12×300'×100'×7' Total 16000000 gals. 25'×16'×8'=3200 C. ft. Sewage Dealt with =45000 gals.	...	16			
Withington ...	...	...	...	250,000									
				250,000									

The Design of Sewage Disposal Works—contd.

PLACE.	FILTERS. Size.	FILTERS. C. ft. per user.	HUMUS TANK. Size.	HUMUS TANK. C. ft. per user.	HUMUS TANK. C. ft. air per gal.	SLUDGE. Digestion Tank.	SLUDGE. C. ft. per user.		ANALYSIS. Suspended Solids.	ANALYSIS. Chlorine.	ANALYSIS. Free Ammonia.	ANALYSIS. Albumen Ammonia.	ANALYSIS. Nitrates Nitrites.	ANALYSIS. 4 Hours Oxygen.	REMARKS.
Manchester Rivers Dept. Report 1914 Withington.	1st contact beds 10×2900 sq. yds. 2nd contact beds 10×2900 sq. yds.	..	..	.	...	.	..	Raw sewage ...	13·7	4·0	1·96	0·42	.	2·82	
								Tank effluent ...	9·1	4·1	1·90	0·35	...	2·23	
								Primary beds ...	...	3·9	1·18	0·15	0·21	0·88	
								Secondary beds...	.	3 9	0·90	0·11	0·37	0·69	
								Tank effluent storm beds ...	...	3 5	1·32	0 23	..	1·39	
								Storm beds ...	.	3 6	1·23	0·15	0·12	0·94	
								Average effluent	...	3 8	0·94	0·11	0·33	0·72	
Davyhulme ...	..	...	..		..	...	.	Crude ...	...	..	...	0·85	...	9·26	Grains per gal.
								Treated ..	...	...	...	0·19	...	2·16	
								Screened sewage	...	..	2·86	1·00	...	10·40	
								Effluent ..	...	.	2·06	0·17	0·30	1·6	
Withington ..	...	...	..	...	...	...	...	Low air Crude...	...	..	1·86	0·46	...	2·73	
								Low air Effluent	...	...	1·62	0·08	0·10	0·51	
								Max. air Crude...	12·6	...	2·10	0·415	...	2·47	
								Max. air Effluent	2·1	...	1·08	0·07	0·45	0·46	

DISCUSSION ON SEWAGE DISPOSAL WORK.

r. G. ranshy illiams.

Mr. G. Bransby Williams said that Mr. Temple's paper was really a complete treatise on sewage disposal in miniature. To him the most valuable part of it was the appendix, in which Mr. Temple had collected a vast amount of information that would be very useful to sewage disposal experts. The paper was not an easy one to comment on adequately, for to go through and deal with all the questions seriatim, would necessitate an address nearly as long as the paper itself. He would therefore content himself with referring to a few points. As regards the alternative of basing the design of sewage works on the number of persons served, and not the number of gallons to be treated, this was undoubtedly the proper system for India, where the sewage was almost always purely domestic sewage. It could not, however, be applied in more advanced countries like England where the sewage problem was complicated by the addition of enormous volumes of trade waste of a great variety of chemical composition, some of them creating great difficulties in the purification works. It would for example be impossible to reduce the sewage of Sheffield, Bradford, Bolton, Brighton, Croydon and Aldershot to a common denomination of number of persons served. In England therefore the question became one of so many gallons to be treated of a certain strength. The sewage disposal problem in India was in fact simple in comparison with that in England, for not only had we hardly any trade waste to deal with, but also the assistance of the climate, which caused biological action to take place much more rapidly than in lower temperatures.

He was afraid he did not altogether agree that sludge from a septic tank was of little manurial value. The sludge from the septic tanks at Dacca had been easily dried and had been pronounced by the agricultural department to have considerable manurial value. So far as his experiments had gone they did not show that the effluent from bio-aeration works had any special advantage from a manurial point of view. In fact the crops grown at Nagpur, which had been irrigated by septic tank effluent had grown better than those irrigated from the effluent from either the Simplex or Activated Sludge plants. The chief advantage of the latter

processes from an economic point of view was the sludge they produced which undoubtedly did possess much greater manurial value than the ordinary septic sludge. Mr. G. Bransby Williams.

He felt he must explain what happened at Gaya, for he was responsible for the design of the septic tanks referred to. This was based on the statement of Colonel Clemesha referred to in p. 68 of the paper that the really important change took place in the preliminary compartment of the septic tank and that the remainder of the tank could probably be much reduced in capacity. These tanks were therefore designed with a large first compartment and a comparatively small second one. However it was found that the estimate of what a tank of this design could do in the way of clarification was too optimistic.

In regard to bio-aeration system, there was only one point that he wished to raise. In England opinion had now crystallized in favour of giving a preliminary treatment before passing the sewage into a bio-aeration plant. It had been stated, although he was not in a position to verify the statement, that the amount of aeration required varied approximately as the square of the amount of organic suspended matter in the sewage, and it was therefore economy to reduce the latter as much as possible by preliminary settlement. The argument probably applied in India and where it was merely desired to produce a really good effluent as cheaply as possible it would probably be found cheaper to pass the sewage through a septic tank before treating it by bio-aeration. This system would however greatly reduce the quantity of surplus sludge and consequently the income that could be obtained by selling it. This was a very important question, and he was not at present prepared to express any opinion on the relative advantages of the two alternatives beyond saying that whichever was adopted should probably depend on local circumstances.

He felt that he had said quite enough and would therefore not deal with any other statements in the paper beyond saying that he considered it a valuable addition to the knowledge of this subject in India.

Mr. A. T. Weston said: Mr. Temple in his paper remarked upon the absence of trade wastes in the sewage discharged from the average town in India. Mr. Temple apparently derived considerable satisfaction from the absence of the particular difficulties which such trade wastes involved. He thought it should be pointed out that Sanitary Engineers would not always be able to Mr. A. T. Weston.

take so light hearted a view of the situation and that the need for providing treatment for trade wastes was one of which a great deal more would be heard in the future as the industrial importance and development of India expanded. Even at this moment one of the municipalities in the outskirts of Calcutta was up against a very difficult problem in regard to the effluent and waste liquors from a number of tanneries employing both the vegetable and chrome bath processes. The tanneries constituted an important asset to the Municipality. They employed labour and paid rates to the community and they naturally expected in return that the public drainage system should remove their waste products without any further trouble to themselves or to the local inhabitants. So far however no satisfactory solution had been found and one of the tanneries at least had to close down in consequence—a state of affairs which was neither satisfactory to the proprietors or to the labour who had been thrown out of employment or to the Municipality. It was not to be expected that each industrial concern should be expert in the disposal of its waste products. The experts in this connection were the Sanitary Engineers in charge of the Drainage and Sewage disposal works provided by the community as a whole. It was therefore up to the members of the Sanitary Engineering profession to take this question of the purification of trade wastes and their disposal in an innocuous manner, seriously into consideration. It was a problem about which much more would be heard in the near future.

MR. M. R. ATKINS congratulated Mr. Temple on his very clear and comprehensive treatment of a difficult subject, and expressed his admiration of Mr. Temple's method of solving all engineering problems by reasoning from first principles instead of from the point where other engineers had left off. He did not agree with Mr. Temple that two storey sedimentation tanks were out of date. Mr. Temple had mentioned the two storey tanks at Colombo. There were several types in use there, and the simplest and least expensive type, formed by subdividing a rectangular tank about 10ft. deep into one lower and two upper chambers by means of inclined slabs of reinforced concrete, had proved most effective. He thought two storey sedimentation tanks and percolating filters were very suitable for use in India as they were far simpler to operate than an activated sludge plant and did not require the same expert supervision. He thought members of the Institution might be interested to hear of an experiment which he had carried out in Colombo in connection with sludge drying. Sludge drying beds had been constructed consisting of a layer of drainage tiles carrying a 9 in. layer of coarse broken stone topped by a 3 in.

layer of stone chips. The sludge was run out on to these beds about 9 in. deep and it dried out very satisfactorily in about 10 days. The dried sludge was then spaded off, but trouble arose in that the stone chips had to be removed and washed after every operation, and there was a considerable wastage of the chips due to their adhering to the dried sludge. To remedy this a single thickness of ordinary coconut matting, as used for flooring, was laid on the top of the coarse stone instead of a layer of chips and weighted down with flat iron bars to prevent its floating. The matting proved to be a perfect filter, passing clear water within 8 minutes of the sludge being run on to it, and was very readily washed and replaced after the removal of the dried sludge. Mr. M. R. Atkins.

THE AUTHOR said in reply that, though he agreed that in present conditions in a country like England it would be very difficult to design sewage works on the basis of number of persons served, such actual statistics as were available showed that the average size of tanks was about 2cu. ft. per head in England. The sludge from septic tanks varied a good deal, but available records gave an average of a nitrogen content of only about 2½ per cent. which was hardly worth carting. It was certainly true that the effluent from bio-aeration works had no special advantage from a manurial point of view. The effluent from the Nagpur septic tanks did not go through filters, and carried a considerable quantity of organic matter; that from the bio-aeration tanks was much more completely purified and carried much less organic matter. The sludge from bio-aeration tanks had enormously greater manurial value. The Author

Preliminary settlement undoubtedly made purification by a bio-aeration process easier, and therefore probably cheaper, in India as well as in England, but it could be carried too far, and leave so much sludge behind that there was scarcely enough left to do the work in the aeration tanks.

In reply to Mr. M. R. Atkin's question why he had lost faith in the two-storied tank, he explained that he had not lost faith in the two-storied process but that he had become convinced that it worked better when the two parts of the process were entirely separated, and when new tanks could be constructed he thought separate tanks would be much cheaper than combined two-storied tanks.

With regard to Mr. A. T. Weston's remark that Sanitary Experts should help in the disposal of trade wastes and thereby

• Author. keep down the cost of the trade products, this only meant that the cost of treating the trade waste had to be borne in a different form by the public at large and possibly at greater cost than if the trade waste was dealt with separately and its cost of disposal borne by the purchasers of the trade products. Sanitary Experts should undoubtedly help each trade to dispose of its own wastes at the minimum cost to the community at large.

With regard to Mr. S. K. Chakravarty's account of his small disposal works and his question why no scum should have formed on one only of them, it was probable that that one was too large for its work and was destroying its own scum by the products of over-septicisation.

THE DRAINAGE PROBLEM OF BOMBAY AND THE PROPOSED NEW MAIN DRAINAGE AND SEWERAGE SCHEMES

BY

V. E. EMMANUELOV, Member.

The position of Bombay situated as it is on a small Island separated from the main land by tidal creeks, at the first glance at the map would appear to be one of the most favourable from the point of view of its sewage disposal and would relieve the city of those problems with which other large towns are usually confronted.

A closer acquaintance with the history of Bombay sewerage however indicates that this is not so and that the question of how and where the sewage of Bombay could best be disposed of has for the last half century been a matter of much controversy among Engineers, Doctors, different Committees and Government Commissions. It has been discussed on several occasions and so far without any definite and practical decision being reached.

The reasons for such continued controversy are many and some of these may be mentioned here. These are:

(1) Contradictory interests of Government, Municipality and other various public bodies,

(2) Shortsighted policy with regard to the possibilities of further expansion and developments of the city and its suburbs and

(3) Permanent reluctance to spend a sufficiently large amount of money to obtain the best solution of the problem with the consequent policy of paliatives, leading only to partial and inadequate measures.

However the drainage of Bombay in spite of numerous alternative schemes from time to time put forward for its solution has, as regards the position of the outfall and the methods of sewage disposal, remained practically the same as it was at the outset.

As in 1867 crude sewage was being discharged into the sea on the western foreshore of the Island at all states of the tide. The same is being done to-day though of course on a very much larger scale.

HISTORY OF BOMBAY DRAINAGE

The exact date, when systematic drainage of Bombay was commenced is not clear; it is known only that certain open water courses were always maintained, doubtless more or less in a perfunctory manner, by which rain water, as well as sewage from inland found their way into the sea, doing so by two large gaps,—one at Worli where some kind of sluices had been constructed and the other—at the place where now stands the Hornby Vellard. As a result of the construction about the year 1842 of this Vellard other sluices were constructed at Lovegrove and a new connection with the upper part of the old open drain was made. Between 1845 and 1857 part of this open drain, approximately between Pydhoni and Bellasis Road, was covered in. In addition to this there existed at that time about 1,268 yds. of covered drains discharging into the harbour and 2,634 yds. of similar drains discharging into Back Bay.

It was not until 1860, from which date Major Tulloch took up the history of the Bombay drainage, that the first general scheme for the drainage of Bombay City as a whole was proposed, Messrs. Wilcox and Tracey being the sponsors for the proposal. In the report of Messrs. Wilcox & Tracey submitted to the Bench of Justices the authors of the scheme objected to the discharge of sewage on the west coast of the Island as being windward and also to the discharge into Back Bay, on account of it being too shallow, but suggested discharge into the Harbour at Wari Bunder and at Carnac Bunder; Colaba, Fort and Malabar Hill, in their opinion, should be drained by independent systems. After approval of this scheme by Mr. R. Rawlinson, a leading Sanitarian of those days, this scheme was sanctioned and work was commenced in 1864. Owing to the persistent complaints of the nuisance caused by the existing drains already discharging sewage into the Harbour, Government appointed in 1866 a Commission to report on the scheme.

Pending the decision of the main question of the Outfalls into the Harbour several minor drainage works were carried out among which was the construction of a low level sewer from Bellasis Road to Lovegrove with a small Pumping Station at that place. These were completed in 1867 thus laying the foundations for the drainage system as it is to-day.

The Members of the Commission were divided in their opinion, Colaba having been suggested by Mr. Ormiston, the Port Trust's

Engineer as the best point for sewage discharge; a new scheme was in consequence prepared, this being done by Mr. Aitken, the then Municipal Engineer.

The Government agreeing with Mr. Ormiston referred this proposal for its consideration to Mr. Rawlinson who gave it as his opinion that sewage discharged at Colaba would return and contaminate the Harbour. This opinion was based on wrong data supplied by Mr. Jaganath Sadashiv as a result of his float observations of the sea currents at Colaba which showed erroneously that the currents during ebb tide set into the Harbour instead of flowing into the open sea, as one would naturally expect and as actually is the case. This extraordinary mistake was discovered only in 1890 by Mr. Baldwin Latham who describes it as the principal cause of Bombay having its main outfall on the western foreshore with all the nuisance arising therefrom.

In 1868 another Government Commission was appointed with the result that an outfall at Colaba opposite the old light house was recommended with the provision that all sewage of the City should be collected into an impounding reservoir to be constructed at that place and to be pumped therefrom into the sea on the ebb tide only. This proposal was sanctioned by Government. Therefore if Major Tulloch takes up the date of Messrs. Wilcox and Tracey's report of 1860 as a commencement of the Bombay drainage history then the report of the first Commission appointed in 1866 by Government may be considered as a commencement of an everlasting controversy with regard to the question as to how and where sewage of Bombay should best be disposed of. Since that date, *i.e.*, 1866 not less than 10 schemes for the solution of the Bombay drainage problem have put forward and no less than 20 different Committees and Commissions have considered the practicability of these schemes from engineering and sanitary as well as financial points of views. However not only the members of the several Committees but the various Committees and Commissions themselves differed in their opinions on the various proposals thus resulting in numerous reports, endless controversy and diverse decisions leading to no end. "There were many schemes all ably advocated and there were the recommendations of the Commissions to do nothing," says Mr. H. A. Acworth in his "History of the Bombay Drainage." 1868.

Of these schemes I shall refer only to the most characteristic from the point of view of the methods proposed for the disposal of sewage and diverse situations of the outfalls.

Of these various schemes the one proposed by Major Tulloch in 1868 and later modified by him in 1871 was the most complete, being also somewhat noteworthy as regards the proposed methods of 1868-1871.

sewage disposal. The main feature of this proposal was the utilization of the crude sewage for land irrigation at Trombay, the effluent it was proposed should be discharged into the Creek. Condemning an outfall at Colaba on economical grounds, Major Tulloch was equally opposed to an outfall at Lovegrove on the score of almost certain nuisance there and he preferred and actually proposed to take sewage as far as possible from the populated areas. Besides by that time the Government having changed their views declared that consent could not be given for the discharge of sewage on the immediate foreshore of the New Military Cantonment at Colaba and that consequently a proposed outfall at this place was inadmissible.

In 1869 another Government Commission was appointed to consider Major Tulloch's proposals with the result that while agreeing to separate storm waters from sewage, as suggested by him they entirely disagreed with his proposal to utilize sewage for land irrigation.

In 1873 Mr. Pedder, the then Municipal Commissioner modifying Major Tulloch's proposal particularly with regard to the application of sewage to land, submitted a scheme in which he recommended the removal of the then existing pumping station discharging sewage into the shallow bay near the sluices of the main open channel at Lovegrove to a new site, and diversion of the sewage outfall further North to the point selected by him on the western foreshore at Worli with a new outfall therefrom to the open sea. He gave as his firm belief that this would be quite sufficient to eliminate all the nuisance that existed and about which there were so many complaints.

Another Government Commission was appointed in 1877 to report on Mr. Pedder's scheme or to suggest another within a cost of 50 lakhs of rupees. In spite of the very strong opinion against the suggested retention of the sewage outfall on the western foreshore, as expressed by the majority of the witnesses who appeared before the Commission, the Commission agreed with Mr. Pedder's proposals and work was commenced in accordance therewith.

By the end of 1880 the main sewer from Carnac Bunder to Lovegrove, a new pumping station and a double barrelled outfall to the sea were completed. But in 1889 another Government Committee was appointed to inquire into the nuisance caused by the existing sewerage system with the result that in 1890 the services of an eminent Engineer and Sanitarian, Mr. Baldwin Latham were requisitioned by the Municipality to report on the existing drainage system of Bombay.

In his report submitted to the Municipal Corporation Mr. Baldwin Latham condemned the discharge of sewage at Lovegrove and pointed out a mistake in the records of the tidal observations at Colaba that had been made and the erroneous deductions that had arisen therefrom. He strongly recommended Colaba as the only proper place for the sewage outfall for the whole City provided that sewage would be stored in a covered reservoir there and be discharged into the sea near the Prongs on ebb tide only.

Another Government Commission was appointed to report on 1891.
his proposals, the result being that the outfall at Colaba was considered to be impracticable owing to the prohibitive cost involved by a very long and deep cutting in rock. Mr. Baldwin Latham at that time agreed that if an outfall at Colaba had been, for sound and considered reasons, found impracticable, then the continuation of the discharge of sewage from an outfall at Lovegrove seemed inevitable.

In 1892 the question as to whether an outfall at Colaba for the 1892.
Colaba sewage only would be advisable was raised, but after much discussion and on Government vetoing the suggestion, it was dropped.

In 1899 at the request of the Corporation Mr. Santo Crimp, an- 1899.
other eminent Engineer and Sanitarian, visited Bombay to advise on various drainage questions particularly that of:

(*a*) the disposal of the storm water of the City

(*b*) the sewage outfall at Lovegrove.

As a result of his investigations and float observations of the tidal currents taken at the place of the existing outfall at Worli Mr. Santo Crimp suggested a transfer of this outfall further North to Worli Point on condition that sewage would be allowed to be discharged at that place during ebb tides.

With regard to the disposal of storm water he suggested the diversion of the main open channel from its point of discharge into Mahim Bay, to a new place at Cleveland Bunder at Worli, as well as the construction of a long weir separating the main open channel from the storm water reservoir at Hornby Vellard. Both works connected with storm water disposal were carried out but not the suggested extension of the sewage outfall.

With the increase of population in the Northern Part of the Island and the absence of a sewerage system in this locality considerable quantity of sullage waters and even of crude sewage from this part of the city have been continuously discharged into the open drains, thus creating a constant nuisance specially noticeable during the dry months of the year.

In 1908 Mr. Maughan, Deputy Executive Engineer, Drainage, prepared a scheme for the sewerage of the Northern part of the Island in which he proposed the erection of a central Pumping station at Dadar with sewers gravitating to this place from surrounding localities stretching on the North as far as Sion and on the South as far as the Ferguson Road Ejectors. After being screened at the station it was proposed that the sewage should be pumped through two 42 ins. diameter cast iron rising mains to Lovegrove, a distance of 2.5 miles, to be finally discharged into the sea, through the existing outfall there.

In 1909, on the representation of the special Committee appointed by Government to report on the possible developments of the City of Bombay the Government passed a resolution in which they referred to the generally recognized unsuitability of Lovegrove outfall as the point of discharge for the sewage, owing to the nuisance to the Western part of the city arising therefrom, and also to their inability to accord permission to the discharge of sewage through an outfall at Colaba. They stated that "the most suitable site appeared to be North East of Sion provided that arrangements could be made to prevent pollution of the Harbour by sewage. It was clearly desirable that the Corporation should consider the advisability of removing the outfall to the North East of Bombay without delay."

In 1912 when Mr. Midgley Taylor, another eminent Drainage Engineer, was in Bombay he was requested by the Corporation to report on the disposal of the storm water of the whole of the City and on the sewerage scheme as prepared by Mr. Maughan for the Northern part of the Island. In 1914 Mr. Midgley Taylor submitted his report in which he fully agreed with Mr. Maughan's proposals for the sewage disposal of the Northern part of the Island. With regard to the disposal of storm water he suggested diversion of the existing main open drain from Lovegrove to meet the Worli channel thus obtaining one common outlet at Cleveland Bunder at Worli. This scheme provided for a storm water pumping station at that place with 10 centrifugal pumps to be actuated by Diesel Engines. Owing to the strong and well founded criticism on both of the proposals offered by the Municipal Executive Engineer and the high cost of the proposed installation of this Pumping station, with all the requisite subsidiary works at Worli, neither proposal was proceeded with. Anticipating in 1916 an increase in the volume of sewage to be disposed of in view of the augmented water supply expected after the completion of raising the Tansa Dam and the proposed scheme for the sewerage of the Northern part of the Island, as well as a desire to minimize potential nuisance thereof caused by the existing outfall at Worli, compelled

the Municipality to consider the question of enlarging the sewage outfall and extending it into deep sea waters.

The suitability or otherwise in this respect of the existing sewage outfall had been fully considered by the consulting engineer, Sir John Wolfe Barry, and condemned, and a new direct line into the deep waters had been suggested.

In 1913 these recommendations having been approved the con- 1913.
struction of the present deep sea outfall at Lovegrove to the length of 4,000 ft. with two 6 ft. diameter steel barrels encased in concrete was commenced. The outfall was not carried out as far as originally intended partly due to the circumstances connected with the war and partly owing to a very unfavourable condition for submarine works to be carried out on such an exposed coast, thus making the execution virtually prohibitive on account of the increased cost. Besides it had been realized that the site of this outfall in an expanded Bombay was far from the ideal or even the best available and in consequence further work on its construction was stopped in 1918 when about 2,000 ft. of this outfall had 1918.
been completed and a different solution of Bombay's drainage problem has been sought.

With the New Tansa completion scheme, for augmenting up to, 90,000,000 galls. per day the City's water supply, in hand and in presence of ever increasing danger of further pollution of the western foreshore, which may be rightly called, "The Lungs of Bombay" with its fresh sea-breeze, magnificent promenades at Worli, Hornby Vellard and Warden Road, excellent and salubrious residential areas along the whole line of this foreshore, the drainage problem of Bombay has to a considerable extent been aggravated, thus persistently demanding an early and satisfactory solution.

But the partial and inadequate character of all former proposals from time to time put forward for the solution of the drainage problem together with an evidently defective state of the existing drainage system and a great expansion of the City during the last few years called for the necessity of proposing a more comprehensive scheme and of greater magnitude.

Such a scheme for the main drainage and sewerage of Bombay as a whole was prepared in 1918 by Mr. James W. Mackison, 1918.
the then Executive Engineer of the Municipality. Mr. Monie, the then Municipal Commissioner before recommending this scheme to the Corporation deemed it advisable to obtain skilled expert's advice with regard to the proposals submitted and on the Corporation agreeing with him, the services of an eminent Engineer

and Sanitarian, Mr. J. D. Watson of Birmingham, were engaged and he subsequently arrived in Bombay in 1919.

As a result of his investigations, enquiries and studies of all the local data and conditions connected with the Bombay drainage problem Mr. Watson submitted in 1920 his first report in which he entirely agreed with Mr. Mackison's proposals and recommended this scheme for execution.

EXISTING DRAINAGE AND SEWERAGE SYSTEMS.

Before continuing on the scheme itself it will be necessary to get acquaintance with the existing drainage and sewerage systems of Bombay, their working conditions, methods employed for sewage and storm water disposal and with all such local data and conditions which served as a basis for the proposed new main drainage and sewerage schemes and led Mr. Mackison to suggest and Mr. Watson to recommend this scheme.

Passing on to the question of the existing drainage and sewerage systems it must be pointed out that the drainage of Bombay is supposed to consist of two separate systems of drains, one being provided for the removal of rain waters and the other for the removal of ordinary domestic sewage and trade effluent. However part of the rain water usually finds its way into the sewers, thus increasing the volume of the sewage in the sewers under monsoon conditions to an extent of about three or four times of the dry weather flow and making the existing drainage system of Bombay in fact only partially separate. At the same time many sewers are connected with the storm water drains, thus making the whole drainage system considerably worse than it might otherwise be.

The Island of Bombay, as it exists now, has been made into one from seven separate islands partly by the silting action of the sea and partly by human agency. As a result of such formation large areas reclaimed from the sea in the central part of the present Island are lying in a large hollow, at levels below High Water mark of the sea, being surrounded by more elevated lands all along the shores, where two parallel ridges of low hills are running: one along the western shore from Malabar Hill Point to Worli, and the other along the eastern shore from Colaba Point to Sion.

STORM WATER DRAINAGE SYSTEM.

Owing to such peculiar physical features of the Island upon which the town of Bombay stands the rain water from these high lands only is being drained by a system of storm water drains discharging directly into the sea at any state of the tide. There

are no less than 40 of such separate outlets discharging either into the open sea on the west, Back Bay in the south, Mahim Bay on the north or into the harbour on the east at different points on the shore. The rain water from all the remaining lands which are lying below the High Water mark of the sea is being drained by a number of different sizes of storm water drains all discharging into two Low level open channels and the storm water Reservoir near the Race-Course. Here it is collected until it is discharged into the open sea through specially provided sluice gates at their outlets and which are opened at the time of ebb tide and during the monsoon only. During the time of high tide as well as during the whole dry season of the year these gates remain closed.

One of these Low level channels with an outlet into the sea at Lovegrove for the drainage of the southern part of the low level lands lying approximately between Sandhurst Road and Byculla, and another one with its outlet near Worli Point for the drainage of the central and northern ports of these lands have been provided.

The defects of such a method of storm water disposal are obvious and being numerous they are still aggravated by the very defective state of the majority of storm water drains in the City. Being in a position to discharge storm water during the ebb tide only these low level channels, owing to their unnecessary sinuous routes and very small gradients, in certain cases reaching 1 in 10,000, are as a matter of fact unable to produce the required velocities in order to empty themselves to the maximum during the short periods of their usual discharge into the sea. They remain stagnant under tide locked conditions with the consequent settlement on their bottoms of all suspended matters they carry which causes a nuisance to the population.

Mr. Watson in his second report on the main drainage and sewerage schemes referring to the existing conditions of the storm water drainage of the City gives the following description of their state:

"I do not exaggerate when I say that I never beheld storm water drains in so foul a state. They have really become huge uncovered septic tanks in which vast quantities of organic matter are being liquified by putrefying or septic organisms. The chief cause of this deplorable condition appears to be that sewage and sullage waters are being discharged into them, that large quantities of filth and cow dung from stables are being flushed into them, and that septicised sewage direct from septic tanks without any effort to oxidize it on land or filters is made to flow

into them thus inoculating the less foul waters in the drains with putrefactive anaerobic organisms which rapidly infect the whole volume. Meanwhile I would direct attention to the obstruction to flow in Lovegrove Creek between the sluice gates and the open sea. Whereas the level of the sill of the gates is about 72.60 T.H.D. the level of the bed of the creek varies from 75 to 82 T.H.D. thus causing much silting in the storm water channel."

As regards the conditions of the contributary drains and other minor feeders distributed all over the city it must be pointed out that most of them are more or less in the same deplorable conditions.

Constructed as a rule with very flat gradients sometimes not covered and of insufficient dimensions these drains do not possess self cleansing velocities, thus being constantly choked and very often overflowing during even comparatively small rainfall. Some of them are very old and having been constructed more than 60—70 years ago are in a dilapidated condition requiring reconstruction. They all are badly silted, thus producing only a small flow not sufficient to meet monsoon requirements.

Most of them are constructed either of stone masonry or of bricks on lime mortar and are covered with rough pieces of stone slabs locally called "dapha" and had their invert plastered only at the time when they were built.

Along the streets, which have their drains constructed underground, storm water entrances with cast iron gratings of the usual type are provided at intervals of 100 250 feet. All of them are provided with catch pits for intercepting road grit and detritus and are trapped to prevent escape of noxious gases from the drains into the air of the streets.

The existence of such arrangements of trapping storm water drains may be explained only by the presence of highly polluted liquid flowing in the drains as a result of sullage and sewage being allowed to discharge into them as well as by insufficient velocities of their flow allowing the organic matters they carry to putrify in the drains prior to the liquor reaching the outlets into the sea. In every properly designed scheme such arrangements are entirely unnecessary and are even most objectionable from a sanitary point of view.

Being for reasons already described provided with catch pits and trapped they are intercepting not so much grit or road metal of which they receive very little from the roads of Bombay the majority of which are tarcoated or asphalted, but the foul waters of the road-washings, as a rule always very dirty, thus allowing

polluted waters to stagnate in the catch pits and to provide very convenient and hideous mosquito breeding places very widely distributed all over the city. In towns like Bombay, where malaria is an endemic disease there is no excuse for the existence of such mosquito nurseries except for only the reasons stated.

There are in existence about 180 miles of storm water drains, their sizes varying from 20 feet by 9 feet double barrelled drains to 9 ins. circular stoneware pipes. Only about 30—40 miles out of the total length of the existing storm water drains are being annually cleaned, but in spite of this more than 300,000 c. ft. of silt are reported to be removed annually therefrom. In spite of the considerable amount of money which is being spent annually for cleaning these drains there is still room to desire their more regular and better cleaning. In 1925-26 about 26 miles of storm water drains were reported as having been cleaned and 30,713 c. ft. of silt removed therefrom. Besides that also Worli, Lovegrove and certain other main open channels were reported as having been cleaned and 350,570 c. ft. of silt were removed therefrom.

SEWERAGE SYSTEM.

As regards the Bombay sewerage it has already been stated that the major part of the Island, *i.e.*, the whole area south of Elphinstone Road has been sewered and that the whole of its sewage by a number of tributary sewers is being conveyed to two main intercepting sewers gravitating to Lovegrove.

Besides that the whole sewage of Colaba district, approximately from the Hotel Majestic southwards is at present dealt with on a Shone sectional system, and where an Air Compressor station situated near the old Cotton Green with air mains to the five ejectors [illegible]ces sewage through rising mains to gravitation sewers and finally discharges it into the main sewer near Wellington Fountain wherefrom it flows by gravitation to Lovegrove.

Owing to the peculiar configuration of the Island, already described, sewage from certain low-lying districts of the town can not flow by gravitation into the main sewers and in all such cases is being lifted locally, as is done at Colaba, by Shone ejectors, the main Air Compressor station being situated at Lovegrove. Eventually the whole sewage is delivered to Lovegrove. After passing there through a detritus chamber where both heavy and floating matters are arrested and removed by mechanical dredgers the whole sewage is lifted at Lovegrove Pumping station and finally discharged into the sea through a deep sea outfall consisting of two 6 ft. diam. steel barrels enclosed in concrete and projecting into the sea for distance of about 2,000 ft.

The remaining part of the Island to the North of Elphinstone Road and North east of Worli channel still remains unsewered although a number of sewers have been already laid there and in such a manner as to fit the proposed new scheme with an outfall at Antop Hill.

The pumping station at Lovegrove consists of four steam driven Beam pumps of 460 B.H.P. for lifting the sewage to an average height of 10 ft. and of two centrifugal electrically actuated pumps of 1,000 B.H.P. for lifting the sewage to an average height of 23 ft. The average dry weather flow is at present equal to about 40,000,000 gallons per day. The two main intercepting sewers gravitating the sewage of the city to Lovegrove are about 5 miles long, ovoid in section, one being 9 ft. by 5 ft. 9 ins. and the other 8 ft. by 5 ft. 3 ins. with a combined maximum discharge of about 100,000,000 gallons per day. They are constructed of brick in lime mortar and are plastered with cement mortar inside.

The tributary sewers are either ovoid or circular in section and are also made of bricks in lime mortar and plastered with cement inside.

As regards minor feeders they are all stoneware pipe sewers varying from 9 ins. to 15 ins. diam., 6 ins. pipes being used for house connections only. All sewers are provided at irregular intervals with manholes of various sizes, shapes and types, are covered with heavy cast iron covers and provided with steps inside for inspection purposes. In view of the continuous silting most of the main sewers are provided along their length at the invert with catch pits for intercepting sand, ashes and road detritus as usually contained in the Bombay sewage. These catch pits being emptied from time to time reduce silting of the invert in the sewers and provide convenient places for silt removal through the manholes constructed over them.

There are in existence about 138 miles of pipe sewers and over 20 miles of main ovoid sewers. During 1925-26 about 70 miles of pipe sewers were reported to have been cleaned and silt removed therefrom amounting to 68,291 c. ft. In the same year 16.46 miles of main sewers were also reported as having been cleaned the silt removed therefrom amounting to 26,354 c. ft. Besides that during the same year 76,496 c. ft. of silt were reported as having been removed from 42 catch pits provided in the sewers.

DEFECTS OF THE EXISTING SEWERAGE SYSTEM

Both from engineering and sanitary points of view there is much to be said against the existing sewerage system of Bombay in general and the method of sewage disposal in particular.

Referring to the present sewerage system of Bombay Mr. Watson in his first report says: "Speaking generally the Bombay sewers so far as I have seen them are well built but I have seen sewers constructed of bricks which I did not think good enough to outlast even a short period loan. The chief fault which I have with the sewers of the City refers to flat gradients and inadequate flushing. The tendency for large trunk and intercepting sewers to silt up received a great deal of my attention. The tendency is general and although the management cleans the sewers at intervals the tendency does not diminish which shows that more drastic remedies will have to be adopted. Many illustrative profiles were submitted to me for examination. They have been taken at various times over a long period and they all prove that even with reasonable treatment the inclination to silt up was very pronounced. It is evident that the faults lay with the gradients insufficient to produce the velocities necessary to carry forward silt."

To illustrate Mr. Watson's conclusions I shall refer to Mr. Baldwin Latham's report of 1892 on "The Sanitation of Bombay" in which he states that "owing to the accumulation of silt the rates of inclination of sewage in main sewers had been on the average reduced from 1 in 1347 to 1 in 2200, a diminution of fall which would alone decrease the velocity of flow by 25 per cent" and that "the sewers of Bombay instead of being put to their legitimate use have been converted into underground receptacles of decomposing filth and instead of flowing with an ever moving and living stream are silted up with decaying matters giving off deadly gases to the positive injury of the health of the people."

And though it was written in 1892 it is sufficiently applicable to the state of sewers to-day. I have seen myself 6 ft. dia. sewers with silt accumulated to a depth of over 3 ft. and with such a ridiculously small velocity of flow as only 9 inches per second.

Most of the sewers are very old and having been constructed to serve the population of the time when they were built are evidently inadequate for the population of to-day increased as it has. At the same time some of them having been designed with a carrying capacity based on a water consumption scarcely above 15 gallons per head per day as in 1881 have become entirely inadequate to accommodate the present discharge, when water consumption has increased to about 50 gallons per head per day.

But whatever the causes for the existence of such defects might be the results are badly felt every now and then.

As a matter of fact insufficient velocities of flow in sewers and their general tendency to silt up are responsible for the increased putrefactive processes. Their accelerated appearance

in the flowing sewage, specially intensified in the favourable conditions of high temperature in India, produce gases with the most noxious odours poisoning the air wherever free outlet for them exist.

This bad smell is felt particularly at the outfall at Lovegrove where over 40,000,000 gallons on an average of such putrid sewage emanating offensive gases is being daily discharged into the sea, thus producing sometimes abominable smells poisoning the whole of the locality.

The general tendency of sewers and storm water drains to silt up besides other drawbacks indicates the necessity of their more frequent cleaning thus involving unnecessary expenditure already amounting to not less than Rs. 50,000 per annum.

Although the length of the sewers and drains annually cleaned is small in comparison with the total length of the existing sewers and drains of the whole city, the large quantity of silt removed therefrom clearly indicates their lack of silt carrying capacity, which reduces the amount of the silt otherwise to be gravitated to the outfalls and there discharged into the sea.

DEFECTS OF PRESENT METHOD OF SEWAGE DISPOSAL.

As regards the sewage outfall itself it must be pointed out that the continuous discharge of crude sewage at all states of the tide on the western foreshore, *i.e.*, on the windward side of the Island is responsible for the contamination of a considerable length of the western foreshore by the accumulation of sewage deposits on the shore and tainted air of this locality by the foul breath of the outfall and polluted waters of the sea. Such deposits can be found everywhere on the foreshore in more or less marked quantities and so far south as Warden Road, *i.e.*, at a distance of about 2—3 miles from the outfall, but considerably less quantities of the deposits are to be found to the North of the outfall.

Accumulation of these deposits is markedly increasing in the shallow bays along the foreshore and is particularly noticeable in the bay at Hornby Vellard, where large quantities of sewage deposits and decomposing sea weed growing at the bottom of the bay are clearly visible at every low tide and can be easily recognized by the smell they produce.

The issue of offensive gases emanating from the sewage deposits decomposing on the shore is greatly increased at the time of low tides when these deposits become exposed to the influence of the sun's rays.

The chief cause of the accumulation of these deposits on the shore is the direction of the existing tidal currents in the sea on the western foreshore of the Island. As will be seen from plate No. 2 the direction of these currents is towards the open sea and northwards during the flowing tide only, being all along the coast line towards the south for the rest of the time. These currents are causing the sewage discharged at the outfall on the ebb tide to flow along the coast line and to be carried by the tide well down and towards the coast in the direction of Malabar Hill. Only flowing tides produce currents which make it possible for the sewage to flow sufficiently far out into the open sea and up the coast line. The velocities of these currents are only about one-eighth to half a mile per hour, the average usually being greatest at the flood tide and the maximum higher on the ebb.

As a result of such movements of the currents and their small velocities the whole of the sewage discharged into the sea at the outfall is moving to and fro along the coast and only during short periods of the flowing tides does it flow sufficiently far out into the open sea and there thoroughly diffuse itself in the large volume of sea water.

Therefore the whole part of the sea nearest to the coast line is being heavily saturated with the sewage perpetually moving to and fro along the foreshore. The line of sewage diffusion in the sea water is clearly visible by the difference of colours of the sea surface, this being very dark at the part where sewage is mixed with it. It represents a continuous strip on the sea surface about 2,000—2,500 ft. wide from the shore at the point of the outfall and gradually diminishing in its width towards the south.

Such inability of the sea currents to transport into the open sea the whole of the sewage discharged at the outfall causes over saturation of the sea water with sewage along the coastal line. The purification process of the sewage diffused in the sea water thus is diminished and delayed due to the lack of oxygen contained in such highly polluted sea water which is necessary for the rapid destruction of the putrescible organic constituents of the sewage.

Besides that the force of the winds should be considered in this case as well. As may be seen from the plate No. 5 the frequency and direction of prevailing winds blowing on the average during 260 days in a year from the sea towards the western shore are also responsible for the accumulation of sewage deposits on the shore by influencing superficial currents of the sea water mixed with the sewage to move towards the coast.

At the same time the force of the prevailing winds blowing with an average daily velocity of about 25 miles is so great, that it prevents organic matter contained in the sewage diffused in the sea water, from rapid sedimentation at the bottom of the sea and keeps it in suspension and under ever moving conditions, thus assisting its transportation further south by the tidal currents. There is consequently fouling of a longer portion of the foreshore by the accumulation of sewage deposits at every convenient place wherever more or less calm waters in the bays permit their sedimentation.

But the same force of the wind besides its drawbacks has also certain advantages. It relieves to a considerable extent the nuisance caused by the abominable smell produced by the sewage discharged and its deposits on the foreshore by blowing tainted air into the atmosphere, thus assisting its rapid dilution by mixing it with large volumes of fresh air.

At the average velocity of the prevailing wind of 32 miles per hour these offensive smells are less felt on the shore and are never felt inland further than half a mile or so from the coast. But in the absence of wind or even with its diminished velocity intensity of the smell is usually considerably increased all over the foreshore and is felt some time much further inland being brought there by occasional atmospheric currents

At the same time, to the misfortune of the people living in the vicinity of the shore, it is noticed that the velocities of the wind are greatly decreasing, if not disappearing altogether usually at time of low tides, *i.e.*, exactly at the time when their increased activities are specially required owing to the maximum intensity of smell at that time produced by the accelerated putrefaction of sewage deposits remaining uncovered by the sea water on the foreshore. I have my own testimony based on my seven years' stay at Lovegrove that at the hottest time of the year and at low tide and with calm weather the smell becomes almost unbearable and certainly is appalling.

For a more complete picture of the existing methods employed for the removal of human excreta and other filth in Bombay, it remains to be mentioned in addition to that already described that to the shame of Bombay as "Urbs prima in Indis" the most offensive system, the halalkhore system, is still in vogue in the Northern unsewered part of the City. I do not propose to describe this system so well known in India, but I shall refer only to Mr. Baldwin Latham's opinion who says:—

"I cannot speak too strongly against such a disgusting and unsanitary system; under it you have the daily accumulation of

dangerous organic matter often near or in very close proximity to the habitation, then the collection and carrying of this matter by men and women who ought to be engaged in some more noble occupation and again you have the cartage of the material through the streets to the disgust of the sensitive public. By the abolition of this system a very large sum of money would be annually saved which is now expended in the collection of the *fæces* of the population."

Those are the main features of the existing drainage system of Bombay with its most characteristic drawbacks and defects of to-day as a result of several unsuccessful attempts to grapple with the drainage problem during the past seventy years.

But what was admissible, to be precise only tolerably in the past, is no longer permissible in view of enhanced engineering knowledge and the higher standard of sanitary requirements of to-day as well as of those vast developments and enormous expansion of the city and its population which were attained during last twenty years.

Therefore nearly a century of experience in the drainage problem of Bombay and our knowledge of already committed mistakes should not be ignored but fully utilized in order to avoid their repetition in future. Particular attention must be paid in regard to all the details of such importance in the conditions prevailing in Bombay, with its distinctive physical features, potential growth of the population, expansion of the City, augmented water supply and many other details playing very important parts as deciding factors in the selection of these or other methods of sewage disposal, position of the outfalls, direction and sizes of various sewers and drains, quantities of liquid to be dealt with, their velocities of flow, etc.

The consideration of some of these factors will now be undertaken.

In determining the sizes of sewers and a pumping station with its relative works, the expected volume of sewage and storm waters must be considered. The volume to be provided for depends on

(1) the maximum flow of actual sewage

(2) the provision required for further expansion and

(3) the rainfall.

The subsoil water should be considered especially on account of the conditions prevailing in Bombay, where this water is very

high and is responsible to a maximum extent for the malaria so prevalent in Bombay. The first two questions are closely connected with the population and water supply of the city and what their ultimate figures are expected to be after, say, fifty or sixty years.

POPULATION.

It has already been pointed out that most of the lands of the Bombay Island as it exists at present, have been made suitable for habitation as a result of reclamation and development work carried out during the last century and especially during the last twenty years. Due to the extensive work undertaken by the Port Trust, Improvement Trust, Development Directorate and the Municipality large areas of new land have been developed as well as new areas reclaimed from the sea. It is worth while noting that while in 1901 the total area of the Island was 14245 acres only, it became in 1911 equal to 14755 acres, in 1921 equal to 15065 acres and at present is calculated to be about 15500 acres excluding areas of the Back Bay Reclamation scheme which is still in progress.

At the same time the population of the City has been increasing more rapidly and while in 1901 according to the census returns of that year the total population was equal to 7,76,006 persons it was in 1921 already equal to 11,75,914 and is supposed to be now approximately 13,00,000 persons.

The following figures are interesting and show the progressive growth of the population of Bombay for the last ninety years.

Year.	Population.
1836	236,000
1872	644,405
1881	773,196
1901	776,006
1911	979,445
1921	1,175,914
1927	1,274,150

Mr. Watson in his first report writing on the population of Bombay states that "growth of the City is not necessarily a natural growth in the sense of its being due to the excess of births over deaths. It may be due rather to the fact that whenever trade is good there is an influx of workers from the mofussil, or interior of the country." This is entirely applicable to Bombay, the large centre of the textile industry and the most important sea-port of the whole of India. This may also be proved by the comparison

of figures showing number of births and deaths and the total population of Bombay for the last fifty-five years as indicated below :—

Years.	1872.	1881.	1901.	1921.	1926.
Total population	6,44,405	7,73,196	7,76,006	11,75,914	12,74,150
No. of births	13,135	16,760	13,520	19,125	21,068
No. of deaths	18,990	22,421	59,495	53,609	31,994

This is also evident from the last census when it was recorded that only 19.56 per cent of the total population of Bombay are people born in this city, while the rest of them are immigrants from various parts of India and foreign countries.

Generally speaking it may be assumed that since 1881 the population of Bombay has increased by about 50 per cent. while its average density for the same number of years showed a considerably lower increase being 54 persons per acre in 1881 and 78 persons per acre in 1921.

At the same time partly due to the habits of oriental people to live close together and partly due to the fluctuating character of the population its density in the different parts of the City is exceedingly variable. While central districts of the City with their mill industry and other commercial undertakings are most densely populated, their density in certain parts being as high as 699 persons per acre in 2nd Nagpada and 736 persons per acre in Kumbharwada, there are districts in the Northern part of the Island with a population of 20 persons per acre only.

Although the population of Bombay has nearly doubled since 1881 and its average density has increased by 24 per cent during the same number of years, the density of the population in most congested districts remains practically the same and in certain cases has even decreased as may be seen from the figures given below :—

Districts.	Density of the population per acre in the years.				
	1881.	1891.	1901.	1911.	1921.
Kumbharwada ...	777·5	699·3	598·0	601·5	736·00
1st Nagpada	323·1	376·1	351·3	216·7	260·21
Bhuleswar	508·0	506·2	398·8	481·1	471·30
Chakla	726·4	624·2	472·7	469 8	489·70
Market	558·2	502·2	318·8	338·6	481·69

Therefore the growth of the population during these years affected to a considerable extent only the less populated districts, particularly those in the North of the Island where large housing and land improvement schemes have been launched by the Government. City Improvement Trust, Port Trust and the Municipality.

The density of the population in these districts is markedly increasing

Districts.	Density of the population per acre in the years.				
	1881.	1891.	1901.	1911.	1921.
Byculla	29·0	50·7	112·6	147·30	160·93
Parel	16·9	25·9	60·4	82·3	107·25
Mahim	18·8	9·9	21·2	23·7	31·85
Worli	10·0	17·2	25·1	49·4	52·69
Mahaluxmi	16·9	45·6	28·1	40·9	59·77

The determination of the expected population of the City and the ultimate figure in fifty years' time is of course a difficult problem and can only be surmised approximately from the past records. This is especially difficult in connection with Bombay where its population is liable to considerable fluctuations depending on the state of trade and commerce. All we have at our disposal for arriving at an approximate total are the census returns for the previous fifty or sixty years, on the basis of which the ultimate figure of the expected population for a similar period of years can be estimated.

In this case, taking into consideration that the population of Bombay has for the last fifty years increased by 50 per cent and looking at the ever-increasing prospects of Bombay in regard to its enormous commercial and trading possibilities as the Gateway of India, it might rightly be assumed that the population will be very nearly doubled during the next fifty or sixty years. Therefore the expected population has been finally accepted by Mr. Watson based on the last census of 1921, to be about 2,000,000 persons, according to which figure all the calculations with regards to the proposed new sewerage scheme are being made, though the original scheme had been calculated for an expected population of 2,689,750 persons.

It has already been mentioned that the density of the population in the most congested districts has been decreasing by migration of the population to the newly developed districts in the Northern part of the City. Taking into consideration all the circumstances including possible developments that may take place in the most congested districts it may be assumed that the population of 2,000,000 persons will be distributed all over the Island more proportionately than at present and its average density may be accepted as varying between 100 to 150 persons per acre. All particulars in regard to the density of the population in different areas are shown in the table No. I.

WATER SUPPLY.

Water supply being the second important factor in determining the capacities of the sewers and other relative works must next be considered.

As in the case of the population so in this case it is very difficult to determine accurately the total quantity of the water that will be ultimately used by the population of the City at the end of the next fifty years. Everything depends upon the quantity of water that ultimately will be used by the population per head per day. The difficulty may be understood by comparison of the figures showing actual water consumption per head per day by the population of different towns.

The following table gives an idea of water consumption in various towns of the world :—

		Gals. per head per day
Italy	Rome	200
U. S. A. America	Chicago	200
	New York	110
	Boston	71
South Africa	Durban	62
	Pretoria	57
	Cape Town	31
China	Shanghai	60
	Hongkong	18
England	Glasgow	57
	London	33
	Leicester	19
Switzerland	Geneva	50
France	Paris	160
Australia	Adelaide	48
	Oakland	30
Japan	Tokio	14
	Kobe	25
Germany	Berlin	15
	Breslau	16
India	Calcutta	90
	Bombay	50
	Madras	28

Until recently the total water supply of Bombay was a little over 40,000,000 gals. per day with an average water consumption of 34.5 gals. per head per day including water used for industrial and all other purposes. After the completion of Tansa Water Works Scheme the water supply of the City increased to 66,750,000 gals. per day as it is at present and is estimated ultimately to be equal to 90,000,000 gals. per day which is the maximum amount the present catchment area of Tansa lake can yield in years of normal rainfall.

The total present daily consumption of 66,750,000 gals. is being distributed for different purposes as follows :—

Suburbs	2,000,000 gals.
Mills, factories and other trades ...	4,250,000 ,,
Port Trust	1,500,000 ,,
Railways	2,000,000 ,,
Govt. properties	1,250,000 ,,
Different public purposes such as Municipal gardens, markets, slaughter houses and other purposes ...	4,250,000 ,,
Milch cattle stables, private liveries and commissions	1,000,000 ,,
Race Course, Hotels	1,000,000 ,,
Building purposes	2,500,000 ,,
Total ...	20,750,000 ,,
Purely domestic purposes	45,000,000 ,,
Grand Total ...	66,750,000 ,,

With the population at present of about 1,300,000 the average consumption is therefore about 50 gals. per head per day which quantity is considered adequate to meet all present needs of the population including industrial and all other requirements.

It is not easy to say also what water supply can be regarded as "normal," as ideas in this respect differ widely in various countries. In certain towns 15 gallons per head per day satisfied the demand while in others two or three times that amount might be accounted for by more lavish use of water. Generally speaking the quantity of water used by the population depends on the climatic conditions of the country, the habits of the people, their standard of living, the industries in which people are employed

and the amount of waste water common to every water supply system.

Mr. Watson in his first report says: "I venture to say that in future it will be found that a supply of not less than 50 gals. per head per day is quite justified in a country where the daily and nightly temperatures prompt the use of water for bathing and other purposes; at the same time I am convinced that with good management 50 gals per head per day is sufficient for any community and I do not exclude either Chicago or New York provided adequate means are taken to check waste."

But the water consumption is not equal throughout the 24 hrs. and being a minimum at night it considerably increases during the day. At the same time it is not equal during the day being the heaviest between the hours of 6 and 9 in the morning and 5 and 8 in the evening when it reaches nearly 75 per cent of the total daily consumption.

RAINFALL AND "RUN OFF."

The rainfall being another important factor in the design of any drainage system will be considered now.

With regard to the determination of the sizes of storm water drains for the volume of storm water to be provided for the volume of rain that falls in the shortest period of time is a matter of great importance and must be considered.

This, of course, is a matter of opinion but much can be done by careful study of the rainfall records over a sufficiently long period of years with special regard to determining the maximum rate of the intensity of the rainfall which can safely be accepted without exceeding the critical economic basis.

From the records of consistent and continuous observations of the rainfall during a period of 73 years carried out by Colaba observatory in Bombay much useful information has been gathered by Mr. Watson and summarized in tables Nos. 2 and 3.

Table No. 3 shows that the average of the maximum hourly rainfall for the last 30 years is 1.76 inches and the average of the maximum daily rainfall is about 6 inches.

The maximum hourly rainfall was 2.91 inches on one occasion, over 2.5 inches on four occasions and over 2 inches on nine occasions for the whole period of the last 30 years.

Such rates of rainfall being exceptional cannot be taken into consideration. Leaving out of consideration all the maximum rainfall records exceeding 2 inches per hour the average maximum hourly rainfall will be only 1.52 inches. Although there has been

rainfall of such intensity nearly every year, having been recorded only on a few occasions not exceeding two or three times in a year, such data should not be taken as deciding factors in the determination of the sizes of storm water drains.

Mr. Watson writing on the rainfall of Bombay says in his first report: "Figures like these lead me to say that the Bombay drainage system should be provided for not less than one inch per hour of rainfall over the area served or rather more than three times the provision made by London where a rainfall of over $1\frac{1}{2}''$ per hour has been registered and where the allowance is less than one third of an inch per hour over the area served. In face of these figures it is wise to provide as many area units with direct storm water outlets as is conveniently possible and to anticipate intelligently the nature of the surfaces—paved or otherwise—on which rain will fall when the area is fully built up."

Having now decided upon the most important point, that of the rate of rainfall to be allowed for, the estimate of the "run off" into the proposed drains must be considered. The fact is that the larger the area to be drained the less is the ratio of "run off" to the maximum rate of rainfall allowed for.

At the same time the more the area is paved and built up the larger will be the rainfall discharged into the drains, i. e., the greater will be the ratio of "run off" to the rate of rainfall allowed for and the reverse.

Taking into consideration all the local conditions and expected developments of the City it might be assumed that most of the City's areas will be paved and built up within the next fifty—sixty years; thus leaving as unpaved only areas occupied by gardens, open spaces, play grounds and yards of houses. We may assume that at least 75 per cent of the remaining areas will be built up and paved. In accordance with these conclusions and with the help of Burkli-Zeigler's formula a diagram has been computed —Plate No. 6— for the expected "run off" from the different sizes of areas and in the conditions of a fully developed Bombay with a maximum intensity of rainfall of 1 inch per hour.

PROVISION FOR RAIN WATERS IN SEWERS.

Having obtained all the data with regard to the expected population, and its density and quantity of water to be used, the volume of sewage expected to be dealt with can be calculated. Generally speaking the volume of sewage should be regarded as not less than the quantity of water supplied to the City, which as it has already been stated has been estimated in the case of Bombay to be not less than 50 gals. per head per day for

years to come.* The inevitable diminution in the volume of sewage as compared with the volume of water consumed, owing to natural causes such as use of water for drinking purposes, evaporation etc., is negligible, the defect being made up by the percolation of subsoil waters into the sewers specially noticeable when new sewers are being coupled with an old sewerage system. Therefore an allowance for the infiltration of the subsoil water to the extent of 15,000 gals per mile of the new sewers has been made in addition to the expected volume of the dry weather flow of sewage.

But, as it has already been pointed out under monsoon conditions a certain part of the rain water finds its way into the sewers, thus increasing to a considerable extent the volume of sewage to be conveyed by them during the monsoon. Besides that the rise in the level of subsoil water under monsoon conditions is also responsible to a certain extent for the increased volume of sewage at that time of the year by the more intensive percolation into the sewer under increased pressure owing to the subsoil water's higher level.

With the evidence of such conditions Mr. Watson considered it necessary to estimate the maximum volume of the sewage to be provided for in the new sewers to be equal to four times their dry weather flow of 50 gals per head per day, i. e., at the rate of 200 gals. per head per day of their maximum flow. On this basis all the calculations for determination of the sizes of sewers and other relative works has been made in the new proposed sewerage scheme.

VELOCITIES OF FLOW.

The main object of every drainage system is the removal and disposal of the storm water, sullage water and sewage proper as expeditiously as possible and in a manner so as not to cause any appreciable nuisance. Therefore the question of the velocities of flow required for the quick removal of sewage and storm waters as well as of the methods to be adopted for their disposal are very important factors to be decided upon. This becomes specially important in hot countries like India as it is evident that the more speedily these are removed the better it will be for the health of the people. It is generally recognized that all the sewers and drains should be constructed with such gradients as will produce self cleansing velocities of flow required for rapid removal of all their contents without silting up the invert.

In this respect more than half a century's experience of the Bombay drainage system is very educative and valuable for the

proposed new drainage scheme of Bombay as well as for any other to be undertaken in India.

As it has already been pointed out most of the existing sewers and storm water drains of Bombay are being continuously silted up as the velocities are insufficient for the rapid removal of the amount of solids usually contained in the sewage and storm water of Bombay. In the majority of cases the velocities of flow as obtained by measurements of the actual flow rarely exceeded 2 ft. per sec., even in the most favourable conditions of flow and were usually much below this figure in more or less normal conditions of their flow. In certain cases they reached even the ridiculously low figure of only 8 or 9 inches per sec.

The velocities obtained by actual measurements after being verified by the hydraulic formulae proved that with the inverts constructed some higher velocities should be obtained than those actually measured and on no account so low as was the case. Such differences between the theoretical velocities and those obtained by actual measurement are explained by the fact of heavy silting of the inverts, thus to a considerable extent reducing the rates of their inclination and consequently reducing velocities of the flow, as well. Moreover it becomes evident that the velocities for which these drains were originally designed and constructed, are nothing like sufficient for the conditions pertaining to Bombay sewage, which as a rule contains abnormally large quantities of heavy solids and requires much higher velocities if a self-cleansing effect is desired.

In consideration of all these facts Mr. Watson suggested higher velocities saying that he is "satisfied that the velocities of flow should be at least 3½ ft. per sec.", that the "Kutter's formula should be used" and that the co-efficient of roughness (n) should be taken at 0.015. Therefore in all calculations of the flow in sewers and storm water drains the co-efficient of roughness has been accepted for

Stoneware pipes above 15" diam.	...	n=0.013.
,, ,, below 15" diam.	...	n=0.010 to 0.011.
Cement plaster ...	...	n=0.015.

COMPOSITION OF THE SEWAGE.

For the purpose of deciding the methods of sewage treatment, if any, to be adopted, and for many other purposes the composition of the sewage has to be considered.

The difference in the composition of the sewage at different places may be as great as that between milk and writing ink, thus

involving a special consideration in regard to its strength. This is specially important when some kind of sewage treatment is required before the resultant effluent is discharged into the waters of a stream as is the case in Bombay. For the purpose of expressing relative strength of different sewages various alternative standards of the composition have been suggested and the one adopted by the Ministry of Health of England has been accepted as sufficient guide in determining the strength of the sewage.

The Ministry of Health characterise the strength of the sewage by the quantity of oxygen absorbed from strong permanganate in 4 hours at 80° Fah.

Thus Strong	sewage	absorbs	17 to 25	parts per 100,000
Average	,,	,,	10 to 12	,, ,, ,,
Weak	,,	,,	7 to 8	,, ,, ,,

At the same time the composition of an average sewage in England as given in the report of the River Pollution Commission is as follows :—

	Parts per 100,000.
Solids in suspension	44.60
Total solids	116.90
Oxygen absorbed	11.00
Free ammonia	6.70
Albuminoid ammonia*	0.63

The particulars given below show an analysis of the typical sewage of Bombay.

	Parts per 100,000
Solids in suspension	41.60
Total solids	249.20
Oxygen absorbed	6.28
Free ammonia	3.07
Albuminoid ammonia*	0.77

From the comparison of figures of oxygen absorbed it will be seen that the Bombay sewage may be regarded as a weak sewage.

As it would be natural to expect, the habits of the people influence the character of the sewage they produce. Sewage in India contains less offensive nitrogenous matter than sewage in

*Estimated by taking 2/7 of the org anic nitrogen.

Europe, due perhaps to the vegetarian diet of the people, and there is less grease and less urine in Indian sewage.

From the comparison of the quantities of solids it will be noticed that Bombay sewage contains more than double the quantity of solids usually found in the sewage in Europe.

This can easily be explained if we recollect that a number of the storm water drains all over the city and particularly open drains are connected with the sewers, thus delivering into the sewers together with rain water, sullage and sewage proper, very large quantities of grit, metal and road sweepings. Besides the habit of the people in India to use sand for cleaning their brass kitchen utensils is also in a great measure responsible for such large quantities of sand being found usually in the sewage of this country.

PROPOSED PLACE AND METHOD OF SEWAGE DISPOSAL.

From the previous statements it will be seen that the total daily quantity of sewage to be dealt with from the expected population of about 2,000,000 persons and at the rate of 50 gals. per head per day of the sewage dry weather flow can be estimated at not less than 100,000,000 gals. per day of D. W. F. or four times that amount, i.e., 400,000,000 gals. per day under monsoon conditions.

The necessity for the disposal of such an enormous volume of sewage leads to the question as to how and where it can best be arranged.

The presence of an already existing sewage outfall at Lovegrove naturally leads to the question whether this outfall can be utilised and if so what method of sewage disposal should be adopted, if any.

From the consideration of the whole case already stated about the existing Lovegrove outfall it is evident that the discharge of more than a double quantity of crude sewage into the sea will lead to the imminent and entire pollution of the whole western foreshore and moreover will be absolutely criminal, being detrimental to the health of the population residing in its vicinity.

The great developments and improvements that have already taken place in this part of the Island and those possible in the future will transform this locality into one of the most desirable and salubrious residential areas of the city, thus making the presence of even the existing outfall, not to speak of any increased discharge or any purification works in this locality with their usual nuisance, most objectionable. Moreover there is not available a sufficiently large area in the vicinity of the Pumping Station,

unless at prohibitive cost, for purification works as will be required if preliminary treatment of the whole city's sewage before its discharge into the sea is to be adopted.

Further extension of the existing outfall into deep sea waters. besides the prohibitive cost, in no case may be considered as a sufficient measure to eliminate the nuisance caused by the sewage discharged into the sea even with the present comparatively small volume of sewage daily discharged there. Therefore the question of utilising Lovegrove outfall for the augmented sewage discharge cannot in any case be accepted as an adequate solution of the drainage problem.

Assuming even that there will be no objections whatever on the practical grounds there are objections on sentimental grounds and they will remain so long as any sewage works and outfall remain at Lovegrove. No matter on what grounds these objections are raised as long as they exist and are expressed in rupees lost by the Improvement Trust on the development schemes at Worli for lack of land buyers, there is ample reason to remove the existing sewage outfall at Lovegrove without taking into consideration any further extension of sewage works there.

Colaba is the most suitable place for the discharge of sewage into the sea. Although this outfall has been recommended on several occasions by competent authorities, it could not be accepted due to the constant objections raised by the Military authorities and the Government's refusal to grant permission to this scheme.

The selection of the Colaba outfall. if such a scheme can be adopted, will not be feasible in the present conditions of an expanded City in general and a thickly populated Colaba peninsula in particular. The position of such an outfall situated at the most southern extremity of the Island will prevent permanently any possible extension further North of the system it serves, as may arise at no distant date in connection with the necessity to dispose of the sewage from such suburbs as Bandra, Ghatkoper, Santa Cruz, Kurla and Chembur.

There would also be no opportunity at Colaba to provide a sufficiently large and isolated area for any purification works required for such a large volume of sewage to be treated before its discharge into the sea.

Therefore only crude sewage can be discharged there and although sewage might go away rapidly and would not easily be returned to the shore owing to the favourable currents prevailing in the sea at that place, the foreshore and the sea would not be free from the solids floating on the water and deposited on the shore.

But the most important point to be considered is, if Colaba is selected as a place for the whole City's sewage outfall, a large amount of money will have to be spent in lifting and relaying in another direction all the existing sewers at present gravitating to Lovegrove. The complete occupation of the whole of the eastern foreshore of the Island by the sea borne trade and shipping industry with their numberless docks, warehouses, railway lines, oil storage tanks, workshops etc., etc., does not on any account permit the possibility of providing sewage outfalls in this locality.

The northern part of the Island with its small and shallow Mahim Bay in any case cannot be regarded as a suitable place for the sewage outfall even with a small discharge into it.

The most careful considerations of the problem as a whole and of all the circumstances taken together led Mr. Mackison to suggest as the best, and in fact the only available place for the sewage disposal, a site on the North Eastern side of the Island with the Pumping Station and all relative purification works at Antop Hill with a sewage outfall towards Trombay for the discharge of the clarified effluent into the harbour water. The selection of Antop Hill for the Pumping Station and the North East of the Island for the discharge of the sewage effluent into the harbour has been influenced by the desire to eliminate to a maximum degree any potential nuisance that might arise from any sewage works and by the possibility, in this case only, of disposing of the whole of Bombay sewage in a most satisfactory and economical manner without causing any injury to the amenities of the city and its harbour.

Writing on this proposal in his first report Mr. Watson says that: "taking all things into account I am satisfied by the facts that the sewage is taken right away from the Island of Bombay" and that "on examining the problem as a whole I am convinced that it is justified and that it will form a permanent solution of the question."

The position of sewage works at Antop Hill has an advantage in addition to many others, of being the most convenient place for any sewage treatment that may be required before the sewage is discharged into the sea. Far away from the populous districts of the City with ample land available for any size of purification works and with the direction of prevailing winds from land towards the harbour, the selection of this place gives ample justification and any nuisance that can reasonably be expected will be the smallest at this site.

The discharge of sewage effluent into the deep harbour waters with their strong tidal currents towards open sea gives full

assurance that the proposed volume of sewage effluent discharged here will be rapidly diffused in the enormous volume of the harbour water refreshed to some extent at every flowing tide.

At the same time any possible expansion of the City's population in future even beyond the proposed rate and the necessity of providing an outfall for the sewage to be received from the suburbs such as Bandra, Santa Cruz, Kurla, Ghatkoper Chembur and others can easily be met at the place of the proposed works at Antop Hill, being most central to all these suburbs with vast possibilities for its further extension.

Moreover being sufficiently near to Deonar, where large areas of low lying grounds are being at present reclaimed by the Municipality with the City's refuse, the purification works at Antop Hill will be provided with an easy means of disposal of the whole amount of the sludge they produce by utilizing it as a liquid fertiliser on the Municipal Farm at Deonar. In this case, the resultant sludge may be pumped from Antop Hill and delivered through the pipes to Deonar.

TREATMENT OF THE SEWAGE BEFORE ITS DISCHARGE.

These are the chief reasons that lead Mr. Mackison to suggest this place on the Island for the disposal of the whole of the City's sewage. As the proposed disposal of such a large volume of sewage by discharging it into the harbour requires some kind of sewage treatment before its discharge the method to be adopted for it has to be considered.

"It would be ideal to render all the sewage of Bombay innocuous and to make it like clean water in appearance before it was allowed to enter the sea, but such ideas are not practicable when dealing with a population of millions. It should be clearly understood that treatment must be made sufficient and only sufficient to warrant the sewage being discharged into an immense harbour like Bombay" says Mr. Watson.

The most careful considerations of all the conditions connected with the sewage discharge into the harbour and all possible methods for its treatment led Mr. Mackison and Mr. Watson to the conclusion that the separation as far as possible of the suspended solids contained in crude sewage by means of screens and upward flow sedimentation tanks, before allowing the sewage liquor to be discharged into the harbour waters, will produce an effluent sufficiently innocuous as not to cause any pollution of the harbour water.

Such effluent being discharged into the harbour at all states of the tide will be easily diffused in the large volumes of clean

tidal waters flowing to and out of the harbour and ultimately will be transported by the existing currents far away into the open sea.

Professor W. E. Adeney in his first report on the proposed sewage disposal by dilution states that "the minimum dilution which would be afforded by the waters of the harbour is over 2,000 volumes or roughly ten times the minimum dilution volumes recommended by the Royal Commission of sewage disposal in England for tidal waters."

Besides the effluent obtained after such treatment as proposed should not contain more than 8 or 9 parts per 100,000 of light and finally divided solid matter in suspension, *i.e.*, in fact there will be no more solid matter in the effluent than there is in the average water supplied in Bombay.

The effluent clarified to such an extent as proposed being amply diluted in clean harbour water will readily undergo its natural biological purificative process produced by the action of myriads of minute organisms always present in such water and collectively termed the "planeton" of the waters.

In conditions like these the quantity of dissolved oxygen contained in the sea waters will be always in excess of the sewage, which is the most essential factor for the continued and healthy activities of the plancton organisms, *i.e.*, for the rapid destruction of the putrescible organic constituents of the sewage matter, and their conversion into harmless, inorganic matter says Prof. Adeney.

The resultant sludge collected in the sedimentation tanks at Antop Hill will be pumped to Deonar where the whole of the city refuse is now being deposited on the low lying lands and it will then be dug into the reclaimed land and mixed with the kutchra, thus producing good arable land for cultivation purposes.

At present only part of this land has been utilised being cultivated with success under different crops such as Indian corn, brinjal, poprie and jowari.

The length of the sludge main, probably a 12 inch cast iron pipe, will be about 5 miles and the quantity of sludge to be conveyed daily will be about 250,000 gals. per million of population.

GENERAL OUTLINE OF THE PROPOSED SCHEME.

The works at Antop Hill will comprise a Pumping Station for lifting sewage to the level required and of a series of specially designed upward flow sedimentation tanks with screens, detritus tanks and other relative works. The average lift of sewage will

be about 30 ft. The total area of land required for the work at Antop Hill will be about 100 acres which will be ample to accommodate all the plant it is proposed to instal there.

The pumping plant will be divided into four batteries each capable of dealing with the dry weather flow. Each battery will consist of three pumping sets to lift about 34 million gallons each per day. The power required will be about 500 B. H. P. for each pumping set and the pumps will be electrically actuated.

With regard to the sewerage system itself designed to convey sewage from various parts of the city it is proposed in continuation of the existing two main sewers at present gravitating to Lovegrove to lay a new main intercepting sewer with a capacity at their junction adequate to pick up the volume of sewage equal to twice the dry weather flow of the sewage to be received from the central part of the city with an area of about 4,350 acres.

Any quantity of sewage in excess of that received under monsoon conditions will be diverted to the existing Lovegrove Pumping Station and there will be pumped through the existing outfall into the sea.

This new main intercepting sewer commencing at Lovegrove will run northwards along Tulsi Pipe Line Road to a point between Dadar and Matunga and then turn eastwards to Wadala and Antop Hill. The sewage from the whole of the western and northern districts of the City including Worli, Mahim, Dharavi, Sion, Matunga and Dadar will flow by gravitation to this main intercepting sewer. A second main intercepting sewer will be laid of sufficient size to receive sewage from eastern part of the city including the Harbour, Back Bay Reclamation and Colaba as far north as Church Gate Street. This sewer commencing at Wellington Fountain will run along Frere Road and Reay Road thence approximately parallel to the Harbour branch railway along proposed new roads, joining the western intercepting sewer near Wadala.

With the construction of this main intercepting sewer the necessity for the existing Shone ejectors system in that part of the city with its costly Air Compressor Station at Lovegrove, troublesome ejectors and leaky air and short lived rising mains will be entirely eliminated.

The present Shone ejector system at Colaba is not in the meantime to be disturbed but the policy of gradually substituting it for gravitation sewers is recommended; it is proposed to gravitate all sewage from Colaba to one pump well near Wellington

Fountain when it will be lifted by electrically actuated pumps into the southern end of the eastern main intercepting sewer.

These are the main features of the proposed new main sewerage schemes.

As regards the proposed new main storm water drainage scheme it must be pointed out that the main feature of this scheme is a proposal to gravitate the storm water to one central place at Lovegrove to which place the Worli-Dadar channel and that from Haines Road are to be diverted and to pump it into the sea at the time of high tides. At the time of low tides storm water will flow in to the sea by gravitation or may be syphoned. Such arrangements will permit of the discharge of storm water into the sea at any state of the tide thus minimising the possibility of flooding in the city otherwise unavoidable in the present conditions of discharge by gravitation through the sluice gates at the time of low tides only.

A new Pumping Station will be erected on the foreshore at Lovegrove for the lift of storm water that has to be discharged at the time of high tides. The total area that will be drained to Lovegrove is about 3,800 acres with a maximum possible discharge at Lovegrove of about 2,700 cft. per sec. or 1,458,000,000 gals per day. For the lifting of this volume of storm water there will be a pumping installation with electrically actuated centrifugal pumps of about 3,000 B. H. P. The maximum lift will be 12 ft. as against high water extraordinary spring tides with sea level at 88.42 ft. above T. H. D. The normal lift for the maximum discharge will be about 5.5 ft.

All the existing main open drains are to be reconstructed, regraded and covered in. Part of the existing open drain between Elphinstone Road and Worli outlet at Cleveland Bunder will be abandoned and a new covered concrete double barrelled storm water drain running from Elphinstone Road along Tulsi Pipe Line Road direct to Lovegrove will be substituted.

On its route to Lovegrove at the crossing with Haines Road this drain will intercept the discharge from the drain running along Haines Road from Jacob Circle and finally will join at Lovegrove another drain coming from Bellasis Road.

The total cost of both proposed schemes is about Rs. 3,00,00,000 as it was roughly estimated at that time. The most careful consideration of all these proposals led Mr. Watson to give his entire approval to them. "Speaking generally, I can and do support the scheme which your Executive Engineer had laid before the

Municipality. It is in my judgment a broad-minded and far-sighted scheme which represent permanency," says Mr. Watson at the conclusion of his report.

At the same time Mr. Clayton, Municipal Commissioner when submitting these proposals, together with Mr. Watson's report on it, for the approval of the Municipal Corporation, at the end of his report says:—

"The Corporation are, I think, greatly indebted to the Government of Bombay, and the India Office for assisting in securing on their behalf the services of so eminent an Engineer as Mr. Watson of Birmingham and one possessing such unique and world-wide practical experience in the design and construction of large sewage disposal works, to advise them with regard to the Bombay scheme and it is very gratifying to have his unqualified approval of the proposals and to be assured that the scheme as designed will, if given effect to, result in a successful and permanent solution of the Bombay sewerage and drainage problems."

FATE OF THE SCHEME.

It seems to be that so broad-minded and far-sighted a scheme, as Mr. Watson rightly calls it, ought to be the closing chapter in the history of the Bombay drainage problem at least for many years to come, so fully does it embrace all the needs not only of to-day, but also of a distant future.

But it is not so and the wheel of history is still turning leaving the drainage problem of Bombay unsolved and a large part of the City without the much needed drainage.

In view of the proposal to discharge sewage effluent into the harbour and the magnitude of the scheme, the Corporation considered it necessary to obtain further expert opinion so, as to be thoroughly satisfied that the present proposals represent more or less a permanent solution of all the present difficulties and will cause no serious pollution to the waters of the Harbour and any nuisance to the population of the eastern shore of the Island.

Accordingly in 1921 the services were secured of two eminent scientists one of them being Dr. W. E. Adeney D.Sc., Professor of Chemistry, who is the foremost bio-chemist in England at present and has had great experience in the effects of the discharge of sewage into the sea, the other being Mr. G. B. Kershaw, who for 12 years has been engaged as engineer of the Royal Commission on sewage disposal in England.

At the same time the Chief Engineer of the Bombay Port Trust submitted his critical report on the proposal to discharge sewage effluent into the harbour and the Trustees of the Port

Trust being vitally interested in the future prospects of the harbour and its amenities and not satisfied with the proposed scheme, had arranged to obtain opinions from two experts to be nominated by the President of the Institution of Civil Engineers. In response to this request Sir Maurice Fitz Maurice and Mr. G. W. Humphrey were nominated.

The Municipal experts and the Port Trust experts in submitting their respective reports on the points raised differed in their opinions as to the feasibility of discharging the effluent into the harbour in the volume proposed, the Port Trust experts opinion being against it. But the Municipal experts fully concurred with all Mr. Watson's recommendations and only slightly modified them by the suggestion to discharge effluent into the harbour at Kurla Creek, *i.e.*, much nearer to the proposed works at Antop Hill.

They considered this place as the most suitable with regard to the possibility of obtaining there more intensified effect of the natural biological process required for the complete and rapid purification of the effluent discharged. In their report submitted to the Corporation in 1922 they state: "we may say at once that the observations, chemical and physical which we have made during our visit to Bombay have gone to confirm the soundness of the view which we have already expressed in our report."

At the recommendation of the Drainage Committee of the Corporation based on the reports of all the experts and conferences they had with them and the Port Trust Executives the whole original scheme, but with the altered place of discharge into Kurla Creek, was sanctioned by the Corporation in 1923.

When the Corporation requested Government to accord their sanction to the proposed discharge of sewage effluent into the harbour, Government replied that owing to the existing controversy, before giving the necessary legal sanction, they had decided to obtain the advice of the best possible independent experts to be selected by the President of the Institution of Civil Engineers. But the President of the Institution in his reply to Government stated, that in view of the fact that the experts already consulted were of such eminence, he was unable to suggest any other.

However at the end of 1923 the Government informed the Corporation that while they would keep a perfectly open mind on the main question whether the sewage of the city should flow into the harbour or to the open sea on the west shore of the Island they could not agree to any discharge of the effluent into Kurla Creek and that it was impossible for them to sanction this scheme in its present shape.

This uncertain state of affairs remained up to the middle of 1924 when a compromised scheme was suggested. Influenced by the circumstances Mr. Watson, when he was in Bombay in 1924, prepared a new scheme and submitted his second report together with preliminary estimates of the cost. Mr. Watson divides this scheme into three separate systems—southern, central and northern. In the case of the southern or Colaba district, as far as Church Gate Street he proposes to eliminate the existing Shone system by a new main intercepting sewer designed for a maximum flow of 48,000,000 gals under monsoon conditions or 12,000,000 gals. of D. W. F. For the lift of this sewage to a height of 25 ft. there will be erected a Pumping Station with a plant of 500 B. H. P. He proposes to construct there a tank sewer outfall, capable of impounding a volume equal to 2/3 of the daily dry weather flow of sewage. The crude sewage will be discharged into the sea at the distance of 5,000 ft. from the shore at a point near Prongs Light House and the periods of discharge will be restricted to four hours during the ebb tide only. 1924.

For the disposal of the sewage to be received from the central parts of the city he proposes to retain the present Lovegrove outfall with the existing Pumping Station and to construct there a covered impounding reservoir with a capacity of 2/3 of the daily dry weather flow, for the storage of crude sewage and to discharge it into the sea at the time of the most favourable currents. The total discharge of sewage proposed at Lovegrove outfall would be about 39,000,000 gals of D. W. F. per day or 158,000,000 gals per day under monsoon conditions. The existing pumping plant at Lovegrove will be supplemented by the addition of a pumping set of 200 B. H. P. and the outfall with two additional 6ft. dia. barrels for a length of 2,000 ft.

The northern part of the city at present undrained and comprising Parel, part of Worli, the whole of Mahim, Dadar, Matunga, Dharavi, Wadala and Sion districts will gravitate their sewage to Antop Hill. For the sewerage of these districts Mr. Watson proposes to construct a main intercepting sewer commencing it from Ferguson Road and running it along Tulsi Pipe Line Road to a point between Dadar and Matunga where it turns eastwards to Antop Hill.

This main sewer will intercept discharge from the existing ejectors at Arthur Road, Delisle Road and Parel Road and the whole sewage from Worli, part of Mahim and Dadar districts brought by separate branch sewers. At Matunga it will meet another intercepting sewer from the north of the Mahim and Dharavi districts. On its route from Matunga to Antop Hill it will intercept one sewer from Wadala and Sion and one from the

Eastern part of the Island at present dealt with on the Shone ejector system. The main intercepting sewer is of a design sufficient for a flow of 191,000,000 gals of sewage per day under monsoon conditions or 48,500,000 gals. per day of D.W.F. which volume will be ultimately delivered to Antop Hill. The volume of sewage to be gravitated to Antop Pumping Station for the first few years is expected to be approximately equal to 8,000,000 gals per day of dry weather flow, or four times that volume under monsoon conditions.

In the meantime a Pumping Station with a plant of 400 B.H.P for the lift of sewage to a height of 29 ft. will be erected at Antop Hill. The whole of the sewage before its discharge into Kurla Creek will be treated at Antop Hill by the activated sludge process, the resultant effluent being purified thereby to such an extent, that no reasonable person in the world could object to its discharge into any stream. It will contain not more than 3 parts of suspended solids per 100,000 parts. The resulting sludge will contain more than 3,000 tons of dry material per annum and the volume of the liquid will be about 200,000 gals per day.

This activated sludge will be pumped to the lands at Deonar through a 12 inch diam. cast iron pipe and utilized as a liquid fertiliser for the irrigation of the Municipal Farm there. Any excess of sludge over the required quantity for the Municipal Farm at Deonar can be sold to cultivators in the form of dry powder. The manurial value of this sludge whether it is used as liquid or as powder is without doubt. Sir John Russell the Principal of the Government experimental Agriculture station at Rothamsted valued at Rs. 52½ per ton the dried sludge while Dr. Fowler of Bangalore valued it at Rs. 60 per ton.

These are the main features of this compromised scheme.

The total cost of this scheme according to the preliminary estimates submitted by Mr. Watson will be Rs. 2,07,32,201 and is subdivided as follows: —

Colaba Outfall	...	...	Rs.	10,25,227
Lovegrove	...	...	Rs.	47,24,212
Antop Hill	...	...	Rs.	1,20,22,762

Although any increase in the volume of sewage discharged at Lovegrove must be regarded as objectionable, persistent suggestions made by certain persons induced Mr. Watson along with his present proposal to submit also an alternative for the drainage of the north of the Island with a discharge into the sea at Lovegrove.

The estimate being higher than in the case of the Antop Hill Scheme this proposal on the ground of cost was not accepted by the Corporation.

After a great deal of consideration and discussion this compromised scheme was accepted by the Trustees of the Port Trust and having been sanctioned by the Corporation was forwarded to Government in 1925 for their approval. 1925.

In 1926 sanction of the Government to the discharge of crude sewage at Colaba, purified sewage effluent at Kurla Creek and sludge at Deonar was accorded. 1926.

With this comes to an end the present history of Bombay drainage problem, but not the end of the long lasting controversy. As a matter of fact by deciding on a compromised scheme resulting in the retention of the present Lovegrove outfall the main drainage problem as a whole remains unsolved.

Mr. H. B. Clayton, the Municipal Commissioner in his report to the Corporation commenting on Mr. Watson's last proposals states :—

"The fact that in his proposals 3 separate outfalls are suggested may, I think, be due to the fact that I have pointed out to him the financial necessity for cutting down capital expenditure within the next few years to a minimum. He must not however be understood in any way to withdraw his former proposals," and further, "I am inclined to believe that the time will come when public opinion will insist on the provision of an alternative scheme for the disposal of Lovegrove sewage even though the nuisance resulting therefrom may be practically non-existing."

BOMBAY MAIN SEWERAGE SCHEME, (1919).

Drainage Area.

Ref. No. on plan.	Description.	Area in acres.	Deduct Open Spaces.		Net Area.	Population.	
			Propor-tion.	Area.		Density per acres.	Total.
	Total area to be drained to Love Grove	4,355	$\frac{1}{3}$	1,452	2,903	300	870,900
1.	Love Grrove to Haines Road ...	242	$\frac{1}{3}$	81	161	200	32,200
2.	Haines Road to Fergusson Road ..	464	$\frac{1}{4}$	116	348	300	104,400
3.	Fergusson Road to line south of Foras Road at Elphinstone Road ..	457	$\frac{1}{3}$	152	305	300	91,500
4.	Line souh of Foras Road to Bombay Dye Works ...	632	$\frac{1}{4}$	158	474	300	142,200
5.	Bombay Dye Works to Dader Road ...	250	$\frac{1}{4}$	62	188	300	56,400
6.	Dadar Road to Bombay Wool Mill ...	162	$\frac{1}{4}$	40	121	300	36,300
a1.	Dharavi North Area	158	$\frac{1}{3}$	53	105	250	26,250
a2.	Do. Central Area ...	212	$\frac{1}{3}$	71	141	250	35,250
a3.	Do. South Area ..	176	$\frac{1}{3}$	59	117	250	29,250
b1.	Mahim Creek to 1st Mahim Road	172	$\frac{1}{4}$	43	129	300	38,700
c1.	Do. 1st Road to Lady Hardinge Road	146	$\frac{1}{4}$	36	110	300	33,000
d2.	Lady Hardinge Road to Wool Mill	226	$\frac{1}{4}$	57	169	300	50,700
e1.	South of Tripartite Road	204	$\frac{1}{3}$	68	136	300	40,800
d2.	Tripartite Road to Naigaum Road ...	331	$\frac{1}{3}$	110	221	300	66,300
d3.	B. B. & C. I. Railway to Vincent Road	77	$\frac{1}{3}$	26	51	250	12,750
h1.	Sion Creek to Mahim Chord	176	$\frac{1}{3}$	59	117	250	29,250
e1.	Dharavi South East . ..	69	$\frac{1}{3}$	23	46	250	11,505
f1.	Mummala North to Chord	94	$\frac{1}{3}$	31	63	250	15,750
g.	Matunga South of Chord	82	$\frac{1}{3}$	27	55	250	13,750
h2.	Do. do. to Main	171	$\frac{1}{3}$	57	114	250	28,500
k.	North Naigaum Road Between Matunga Vincent Road and Boewada ..	77	$\frac{1}{3}$	26	51	250	12,750
11.	Matunga between Vincent and Boewada Roads and North of Main	125	$\frac{1}{3}$	42	83	250	20,750

	Colaba to Mayo Road	1,595	$\frac{1}{3}$	532	1,063	200	2,12,600
m1.	Mayo Road to Fort Street ...	322	$\frac{1}{3}$	107	215	300	64,500
m2.	Fort Street to Carnac Road ...	136	$\frac{1}{3}$	45	91	300	27,300
m3.	Carnac Road to Elphinstone Road ...	135	$\frac{1}{3}$	45	90	300	27,000
m4.	Elphinstone Road to Dockyard Road	294	$\frac{1}{2}$	147	147	300	44,100
m5.	Dockyard Road to Tank Bunder Road	316	$\frac{1}{2}$	158	158	300	47,400
m6.	Tank Bunder Road to Kalachowki	548	$\frac{1}{3}$	183	365	200	73,000
m7.	Kalachowki to Curry Road Extension	504	$\frac{1}{3}$	168	336	200	67,200
m8.	Curry Road Extension to Tripartite Road	383	$\frac{1}{3}$	128	255	300	76,500
m9.	Tripartite Road Extension to Naigaum Cross Road Extension	406	$\frac{1}{3}$	135	271	300	81,300
m10.	Naigaum Cross Road Extension to Main	104	$\frac{1}{3}$	35	69	300	20,700
n1.	Between Boewada and Harbour Branch to Main	150	$\frac{1}{3}$	50	100	250	25,000
q1.	Sion North-east side Vincent Road to Creek	108	$\frac{1}{3}$	36	72	250	18,000
q2.	Rowlee Hill Area	282	$\frac{1}{3}$	94	188	250	47,000
q3.	Mudly Antop Area	212	$\frac{1}{3}$	71	141	200	28,200
p1.	Wadala Station Area ...	309	$\frac{1}{2}$	155	154	200	30,800
		14,657	......	......	......	... ...	2,689,750

DODD DODD & WATSON,
M. M. Inst., C.E.,
BIRMINGHAM.

RAINFALL IN INCHES.

Average For Decades from 1850-1918.

Data by Government Observatory,

COLABA.

Decade.	May.	June.	July.	Aug :	Sept :	Oct :	Nov :	Total of 7 months.	Total for the year.	No. of Rainy days in year.
1850-59 ..	·50	20·65	23·52	9·47	9·34	1·97	·21	65·66	66·83	99·4
1860-69 ...	·08	17·10	23·93	17·59	9·40	2·37	·22	70·69	70·83	102·4
1870-79 ..	·71	20·27	22·76	13·35	11·38	1·70	·56	70·75	7 ·15	102·1
1880-89 ...	·24	19·94	28·20	12·98	11·12	3·10	·43	76·01	76·40	110·5
1890-99 ..	·70	19·84	23·02	13·71	12·48	1·36	·42	71·53	71·83	109·4
1900-09 ...	·78	16·23	25·55	13·10	8·09	·84	·10	64·69	64·98	96·8
1910-18 ...	·15	19·69	18·95	13·73	10·96	3·01	·56	67·05	68·57	98·6
Average ...	·45	19·10	23·71	13·42	10·31	2·05	·36	69·40	70·09	102·7

M/S.

DODD DODD & WATSON,
M. M. INST. C. E.,
Birmingham.

RAINFALL IN INCHES.

Data by the Government Observatory, Colaba, BOMBAY.

YEAR.	Total Rainfall.	Maximum fall in one day.	Maximum fall in one hour.	No. of days on which over 4 to 8 ins. fell.	No. of days on which. over 8 ins fell.
1889	67·84	4·04	1·18	1	...
1890	65·18	4·61	1·29	1	...
1891	77·18	5·82	1·59	4	...
1892	95·12	5·43	1·85	4	...
1893	67·24	4·97	1·50	1	...
1894	66·85	4·77	1·60	1	...
1895	67·59	6·82	1·42	3	...
1896	87·65	6·21	2·10	1	...
1897	81·53	4·92	1·85	3	...
1898	74·09	5·13	1·60	5	...
1899	35·90	6·58	2·34	1	...
1900	69·12	8·04	1·53	3	1
1901	75·32	6·55	2·89	2	.
1902	71·97	6·74	1·36	2	...
1903	84·49	6·03	1·86	1	...
1904	33·42	3·33	1·20	.	...
1905	33·66	4·00	2·11	1	...
1906	56·30	4·89	1·35	2	.
1907	100·78	8·84	2·91	7	1
1908	53·54	4·30	1·11	2	..
1909	71·22	4·07	1·58	1	..
1910	67·86	8·14	2·69	2	1
1911	46·51	4·78	2·68	3	...
1912	54·05	7·86	2·33	3	...
1913	70·96	5·50	2·25	4	...
1914	81·62	6·28	1·65	3	...
1915	77·68	11·41	1·85	3	2
1916	86·05	7·60	1·64	3	...
1917	99·76	5·96	1·65	4	...
1918	35·54	4·98	...	2	...
1919	68·32	8·74	...	2	1
AVERAGE	71·75	6·04	1·76	...	...

DODD DODD & WATSON,

M/S. M. M. INST., C. E.

Birmingham.

BOMBAY MAIN SEWERAGE SCHEME (YEAR, 1924)

Drainage Area.

Portion of Main Sewer.		Area Drained to This Portion.					
Designation of the plan.	Description.	Designation of the plan.	Description.	Area in acres.	Density.	Population.	Remarks.
			TO BE DRAINED TO ANTOP HILL.				
A.B.	From the Ejector at Arthur Road to Fergusson Road	A	Area drained to the Ejector at Arthur Bridge	400	150	60,000	
B.C.	From Fergusson Road to Tulsi Pipe Line Road	A	Area drained to the Ejector at Fergusson Road	500	150	75,000	
C.C.	Tulsi Pipe Line Road to Globe Mills Passage	A 2	Western part of the area at present drained to the Ejector at Carol Road	100	150	15,000	
C.D.	From Globe Mill passage to Elphinstone Road	W 2	North Worli Area	520	125	65,000	
D.E.	From Elphinston Road to Nardulla 50' Road	A 2	Eastern part of the area A 2 ..	400	150	60,000	Some portion of this area (A2") is to be eventually added to Dd area.
E.F.	From Nardulla Road to Dadar Road	M 1	South Mahim Area	180	125	22,000	
		M 2	" " "	200	125	25,000	
F.G.	From Dadar Road to proposed 6' Road		" " "	120	125	25,000	
G.H.	From proposed 6' Road to Junction with sewer from the North	M 4	" " "	160	125	20,000	
H.J.	From the junction with sewer from North to the junction with sewer from Dadar and Matunga	M 5	North Mahim	160	125	20,000	
		M 6	" "	180	125	22,500	
		M 7	" "	160	125	20,000	
		D h	Dharavi	520	100	52,000	
J.K.	From the junction with sewers from Dadar to Matunga to the junction with the east branch ..	M t	Matunga	360	125	45,000	This area Dd will include eventually some of A2 area.
		S i	Sion	340	125	42,500	
		D d	Dadar and Parel	440	150	66,000	

E	From junction with eastern branch to the junction with the sewer from Gowari	W d	Wadala (M)	280	125	35,000
		H 1	Area east of P. T. Railway between Antop and Sewri Fort ..	240	50	12,000
		H 2	P. T. Sewri Reclamation area ..	800	50	40,000
		A 4	Area drained to Eastern ..	180	150	27,000
		A 5	Ejectors ..	180	125	22,500
		A 6	" " " ..	140	150	21,000
		A 7	" " " ..	260	150	39,000
		A 8	" " " ..	110	150	16,500
		H 3	Dockyards area between Carnac and Malet Bunders	180	50	9,000
K. 1	From the junction with the sewer from Gowari to Antop ..	G	Gowari	400	100	40,000
			TO BE DRAINED TO ANTOP HILL DIRECTLY.			
		S 1	Saltpans South of Antop Hill ..	600	100	60,000
		S 2	Do. North "	900	100	98,000
		R	Proposed Reclamation to Trombay	1,600	50	80,000
			TO BE DRAINED TO LOVE GROVE.			
		C	Central area to be drained to L. G.	4,660	150	700,000
		W 1	South Worli Area	260	125	32,500
		N	Area to be drained to Colaba ..	2,000	125	250,000
		Mc	Malabar hill area	240	125	30,000
			About ..	18,800		2,100,000

TABLE No. 1. SHOWING SIZES OF SEWERS REQUIRED FOR VARIOUS NUMBER OF POPULATION OF THE AREAS SERVED.

Assumed Flow of Sewage is 200 Gallons Per Head Per Day of the Population. Velocities of Flow in Sewers Vary Between 3 ft. Per Sec. and 3·5 ft. Per Sec.

SMALL CIRCULAR SEWERS.

Density of population per acre.	50		100		150		200		250		300		POPULATION SERVED.		Flow in C. ft. per sec.	
Size of pipes	AREAS DRAINED AT															
	V. ft. per sec.		V. ft. per sec.		V. ft. per sec.		V. ft. per sec.		V. ft. per sec.		V. ft. per sec.					
	V= 3.5 ft.	V= 3 ft.	V= 3.5 ft.	V= 3 ft.	V= 3.5 ft.	V= 3 ft.	V= 3.5 ft.	V= 3 ft.	V= 3.5 ft.	V= 3 ft.	V= 3.5 ft.	V= 3 ft.	V= 3.5 ft.	V= 3 ft.	Q at V= 3.5 ft.	Q at V= 3 ft.
9"	84.	72.	42.	36.	28.	24.	21.	18.	17.	14.5	14.	12.	4,200	3,600	1·55	1.33
12"	150.	120.	75.	60.	50.	40.	37.5	30.	30.	24.	25.	20.	7,500	6,000	2·75	2.35
15"	240.	200.	120.	100.	80.	67.	60.	50.	48.	40.	40.	33.	12,000	10,000	4·30	3.68
18"	324.	288.	162.	144.	108.	96.	81.	72.	65.	58.	54.	48.	16,200	14, 400	6·18	5.30
21"	455.	390.	227.	195.	152.	130.	114.	98.	91.	78.	76.	65.	22,750	19,500	8·42	7.22
24"	600.	500.	300.	250.	200.	166.	150.	125.	120.	100.	100.	80.	30,000	25,000	11·00	9,43
30"	930.	800.	455.	400.	310.	266.	230.	200.	185.	160.	155.	133.	45,000	40,000	17·23	14.73

REMARKS.—For smaller size sewers (up to 24") no lower figures than those of column 2 (100 Density) should be used allowing the sewers to run half full, or even the figures of the third column can be taken as minimum, allowing for eventual leakages.

TABLE No. II. SHOWING SIZES OF SEWERS REQUIRED FOR VARIOUS NUMBER OF POPULATION OF THE AREAS SERVED.

Assumed Flow of Sewage is 200 Gallons Per Head Per Day of the Population Velocities of Flow in Sewers Vary Between 3 ft. Per Sec. and 3·5 ft. Per Sec.

CIRCULAR SEWERS.

Size.	Q at V = 3·5 ft.	Q at V = 3 ft.	Population Served.	
			V 3·5 ft.	V 3 ft.
2'6"	17·23	14·73	45,000	40,000
2'9"	18·8	17·8	51,000	48,000
3'	24·7	21·2	67,000	57,000
3'3"	29·0	24·9	77,800	67,000
3'6"	33·6	28·8	90,000	78,000
3'9"	38·6	33·0	104,000	98,000
4'	44·2	37·8	120,000	102,000
4'3"	49·7	....	134,000	......
4'6"	55·7	......	150,000	......
4'9"	61·9	......	167,000	......
5'	68·5	......	185,000	......
5'3"	75·6	......	204,000	......
5'6"	83·5	......	225,000	......
5'9"	91·1	......	246,000	......
6'	99·1	......	267,000	......
6'3"	107·5	......	290,000	......
6'6"	116·2	......	314,000	......
6'9"	125·2	......	338,000	......
7'	134·7	......	364,000	......
7'3"	144·6	......	390,000	......
7'6"	154·6	......	417,000	......
7'9"	165·2	......	446,000	......
8'	176·0	......	447,000	......
8'3"	187·2	......	505,000	......
8'6"	198·5	......	536,000	......
8'9"	210·5	......	567,000	......
9'	222·5	......	600,000	......
9'3"	235·0	......	635,000	......
9'6"	248·0	......	670,000	......
9'9"	261·5	......	705,000	......
10'	175·0	......	742,000	......

TABLE No. III. SHOWING SIZES OF SEWERS REQUIRED FOR VARIOUS NUMBER OF POPULATION OF THE AREAS SERVED.

Assumed Flow of Sewage is 200 Gallons Per Head Per Day of the Population. Velocity of Flow in Sewers 3 ft. Per Sec.

HORSE SHOE SEWERS.

Height.	Q at V - 3·5 ft. per sec.	Population Served.
10'	320	810,000
10'3"	336	910,000
10'6"	352	950,000
10'9"	370	1,000,000
11'	387	1,045,000
11'3"	405	1,090,000
11'6"	420	1,135,000
11'9"	440	1,185,000
12'	460	1,240,000
12'3"	480	1,295,000
12'6"	500	1,350,000
12'9"	520	1,405,000
13'	540	1,460,000
13'3"	560	1,510,000
13'6"	581	1,570,000
13'9"	603	1,630,000
14'	627	1,695,000
14'3"	650	1,755,000
14'6"	673	1,820,000
14'9"	697	1,880,000
15'	720	1,950,000

TABLE No. 1. SHOWING GRADIENTS TO BE PROVIDED FOR OBTAINING REQUIRED VELOCITIES IN VARIOUS SIZE SEWERS.

Desirable Velocity is 3·5 ft. per second.

SMALL CIRCULAR SEWERS.

Size.	Area.	H. M. D.	FROM			TO					
			Gradient.	V. when full.	V. when 1/3 full.	Gradient.	V. when full.	V. when 1/3 full.	Gradient.	V. when full.	V. when 1/3 full.
				STONE WARE PIPES		Velocity calculated on Kutter's formula with n=0·013					
9"	0·442	0·188	1-100	3·5	2·8	1-120	3·2	2·6	1-150	2·8	2·3
12"	0·785	0·250	1-150	3·5	2·8	1-180	3·2	2·6	1-200	2·8	2·4
15"	1·23	0·312	1-200	3·6	2·9	1-250	3·3	2·6	1-300	2·9	2·4
18"	1·77	0·345	1-250	3·7	3·0	1-300	3·4	2·7	1-350	3·0	2·5
21"	2·40	0·451	1-300	3·8	3·1	1-375	3·4	2·7	1-450	3·1	2·5
24"	3·14	0·500	1-350	3·8	3·1	1-450	3·4	2·8	1-500	3·1	2·6
				CONCRETE.		Velocity calculated on Kutter's formula within=0·015					
2',6"	4·91	0·625	1-400	3·6	2·9	1-500	3·3	2·6	1-600	3·0	2·4
2',9"	3·94	0·688	1-450	3·6	2·9	1-550	3·3	2·6	1-650	3·0	2·4
3',0"	7·07	0·750	1-500	3·6	2·9	1-600	3·3	2·6	1-700	3·1	2·5
3',3"	8·50	0·813	1-550	3·6	2·9	1-650	3·4	2·7	1-750	3·1	2·5
3',6"	9·62	0·875	1-600	3·7	3·0	1-700	3·5	2·8	1-800	3·1	2·5
3',9"	11·00	0·938	1-650	3·8	3·1	1-750	3·5	2·8	1-900	3·2	2·6
4',0"	12·6	1·000	1-700	3·9	3·2	1-800	3·5	2·8	1-1000	3·2	2·6

TABLE No. II. SHOWING GRADIENTS TO BE PROVIDED FOR OBTAINING REQUIRED VELOCITIES IN VARIOUS SIZE SEWERS.

Desirable Velocity is 3·5 ft. per second.

CIRCULAR SEWERS CONCRETE.

Velocity as per Kutter's Formula, $n = 0{\cdot}015$.

Size.	Area.	H. M. D.	Gradient.	V. when full.	V. when 1/3 full.
4' 3"	14·20	1·06	1-850	3·5	2·9
4'—6"	15·9	1·13	1-900	3·6	3·0
4'—9"	17·7	1·19	1-950	3·6	3·0
5'—0"	19·6	1·25	1-1000	3·6	3·0
5'—3"	21·6	1·31	1-1100	3·6	3·0
5'—6"	23·8	1·38	1-1200	3·6	3·0
5'—9"	26·0	1·44	1-1300	3·5	2·9
6'	28·3	1·50	1-1400	3·5	2·9
6'—3"	30 7	1·56	1-1500	3·6	2·9
6'—6"	33·2	1·63	1-1600	3·5	2·9
6'—9"	35·8	1·69	1-1600	3·0	3·0
7'	38·5	1·75	1-1700	3·5	2·9
7'—3"	41 3	1·81	1-1800	3·5	2·9
7'—6"	44·2	1·88	1-1800	3·6	3·0
7'—9"	47·2	1·94	1-1900	3·5	2·9
8'	50·3	2·00	1-2000	3·5	2·9
8'—3"	53·5	2·06	1-2000	3·6	3·0
8'—6"	56·7	2·13	1-2100	3·5	2·9
8'—9"	60·1	2·19	1-2200	3·5	2·9
9'	63·6	2·25	1-2200	3·6	3·0
9'—3"	67·2	2·31	1-2300	3·0	3·0
9'—6"	70·9	2·38	1-2400	3·6	3·0
9'—9"	74·7	2·44	1-2400	3·7	3·1
10'	78·5	2·50	1-2500	3·6	3·0

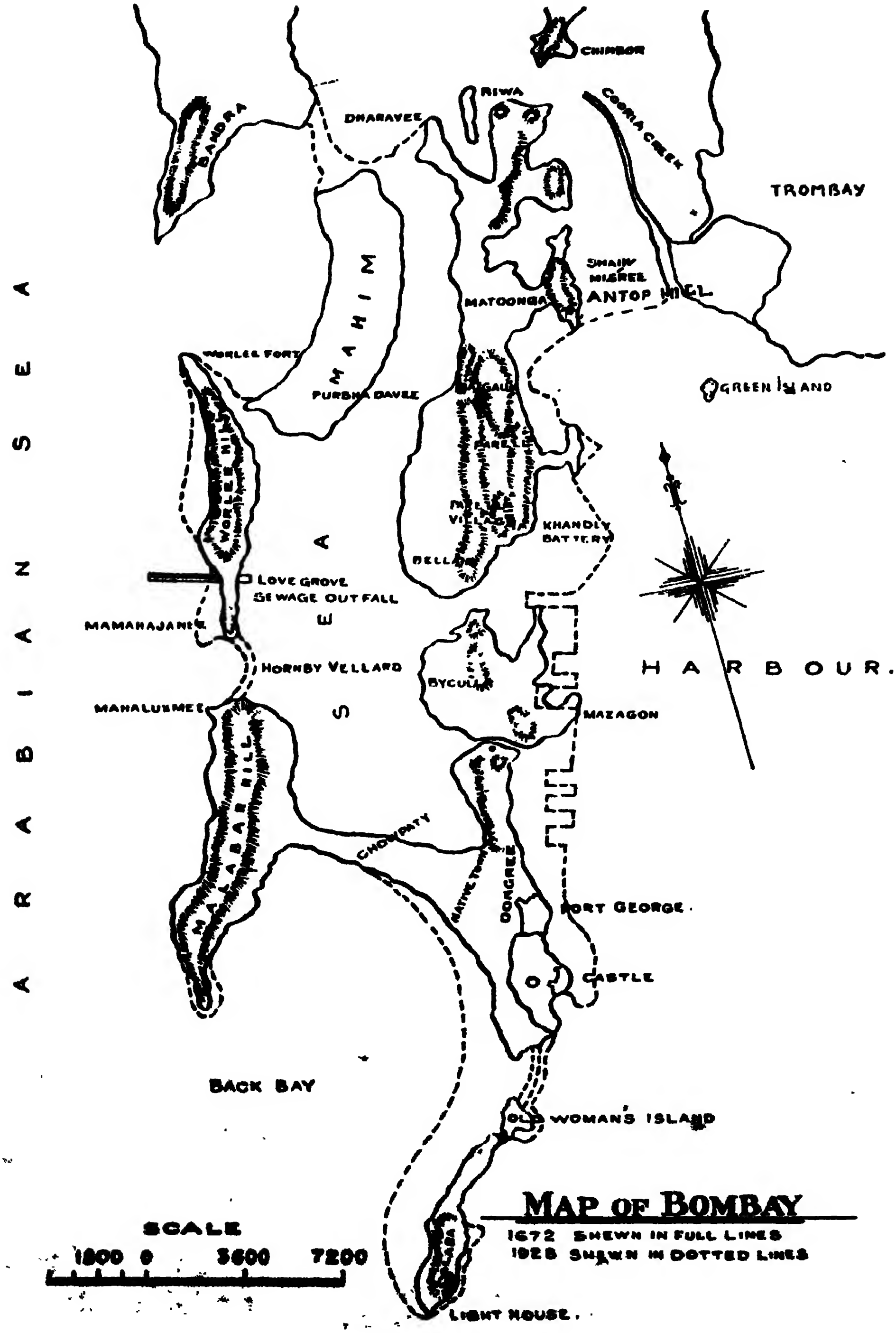
TABLE No. III. SHOWING GRADIENTS TO BE PROVIDED FOR OBTAINING REQUIRED VELOCITIES IN VARIOUS SIZE SEWERS.

Desirable Velocity is 3·5 ft. per second.

HORSE SHOE SEWERS CONCRETE.

Velocity as per Kutter's Formula, n = 0·015.

Height.	Area.	H. M. D.	Gradient.	V. when full.	V. when 1/3 full.
10'	91·3	263	1-2800	3·6	3·1
10'-3"	96·0	270	1-2900	3·6	3·1
10'-6"	100·8	276	1-3000	3·6	3·1
10'-9"	105·5	283	1-3100	3·6	3·1
11'	110·5	290	1-3200	3·6	3·1
11'-3"	115·5	296	1-3400	3·5	3·0
11'-6"	120·0	303	1-3500	3·5	3·0
11'-9"	126·0	310	1-3600	3·5	3·0
12	131·5	316	1-3700	3·5	3·0
12'-3"	137·0	323	1-3800	3·5	3·0
12'-6"	142·5	329	1-4000	3·5	3·0
12'-9"	148·3	336	1-4100	3·5	3·0
13'	154·3	342	1-4200	3·5	3·0
13'-3"	160·0	349	1-4300	3·5	3·0
13-6"	166·0	355	1-4400	3·5	3·0
13'-9"	172·5	362	1-4500	3·5	3·0
14'	179·0	369	1-4600	3·5	3·0
14'-3"	185·5	375	1-4700	3·5	3·0
14'-6"	192·0	382	1-4800	3·5	3·0
14'-9"	199·0	388	1-4900	3·5	3·0
15'	206·0	395	1-5000	3·5	3·0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RIWA
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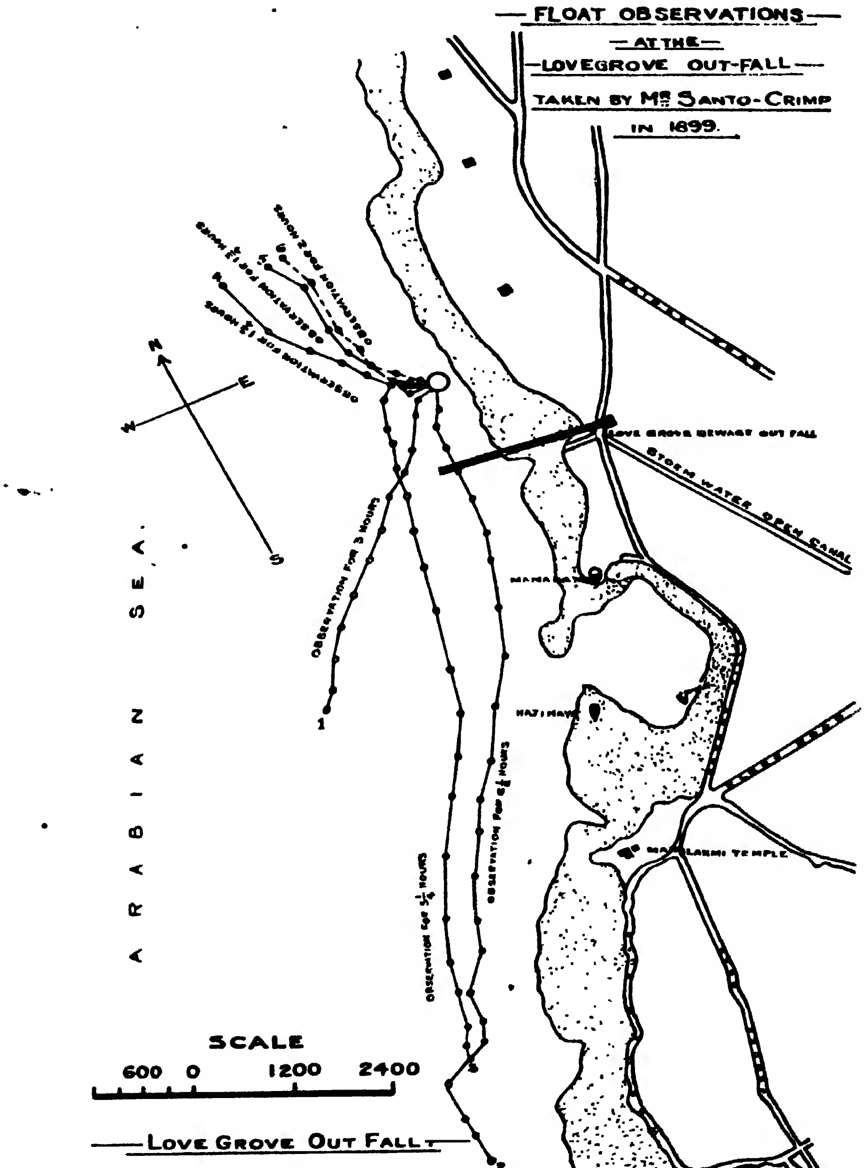
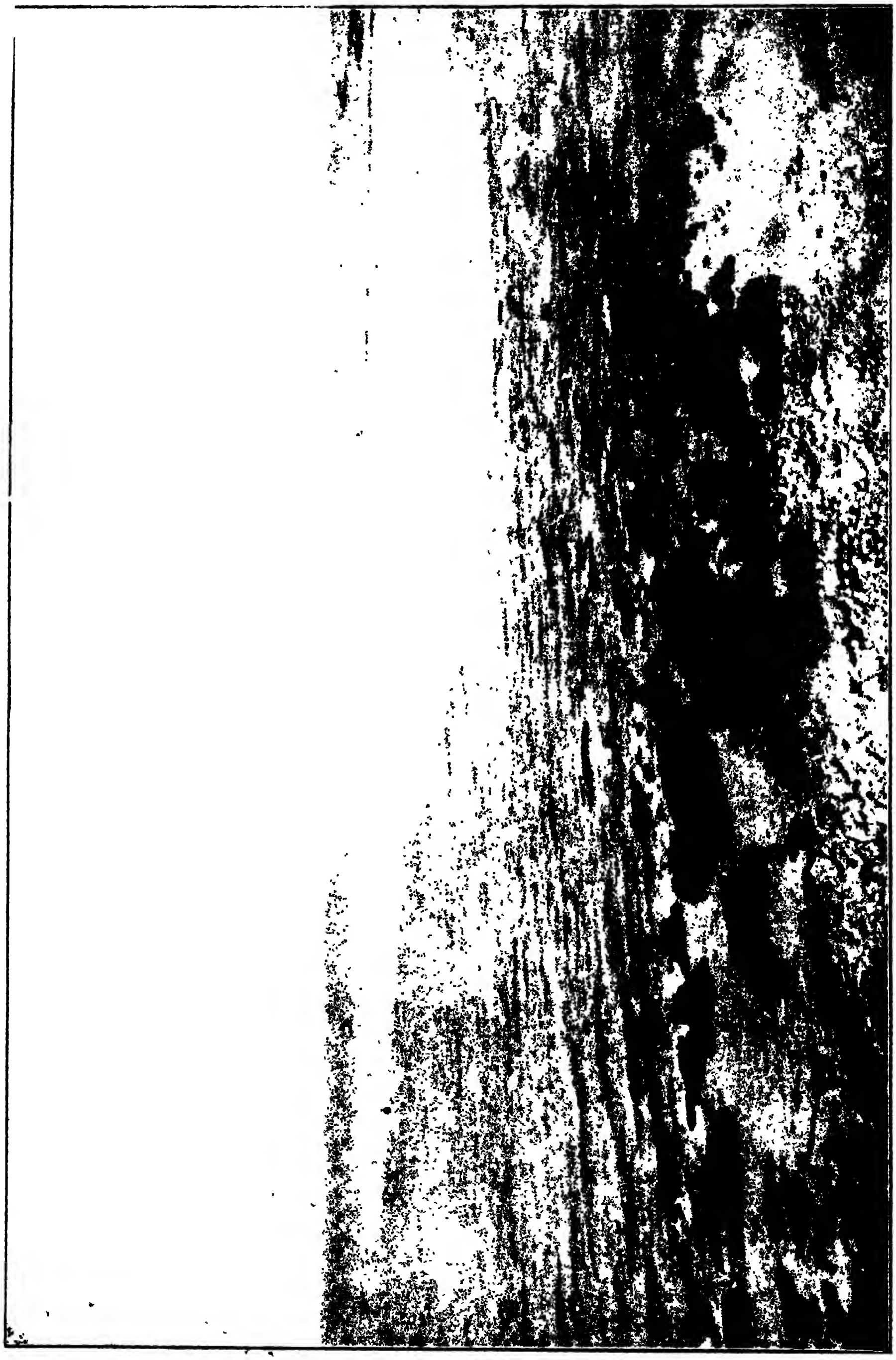
BANDRA
DHARAVEE
TROMBAY
MAHIM
SHAIV
MISREE
MATOONGA
ANTOP HILL
WORLEE FORT
PURBHA DAVEE
GREEN ISLAND
ARABIAN SEA
WORLEE HILL
PARELL
VILLAGE
KHANDLY
BATTERY
BELLA
LOVE GROVE
SEWAGE OUT FALL
SEA
MAMAHAJANEE
HORNBY VELLARD
HARBOUR.
BYCULLA
MAHALUXMEE
MAZAGON
MALABAR HILL
CHOWPATY
DONGREE
NATIVE TOWN
FORT GEORGE
CASTLE
BACK BAY
OLD WOMAN'S ISLAND
MAP OF BOMBAY
1672 SHEWN IN FULL LINES
1928 SHEWN IN DOTTED LINES
SCALE
1800 0 3600 7200
LIGHT HOUSE.

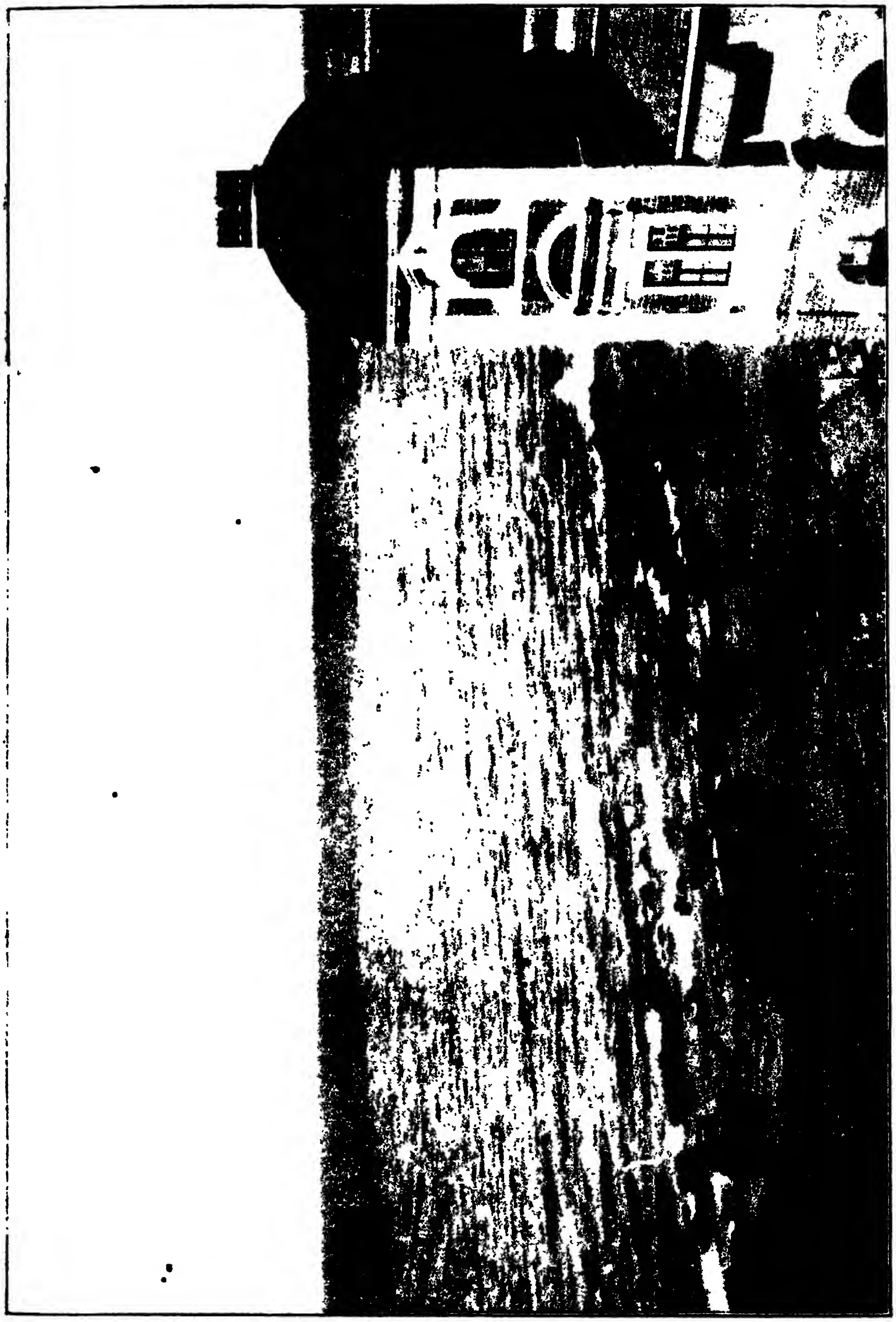


Love Grove Out Fall

Observation No.	Date	Time of high water at Apollo Bunder	Time of low water at Apollo Bunder	Observation began	Observation ended	State of sea	Wind
1	1899 Dec. 9th	3 25 A.M.	10 1 A.M.	7 5 A.M.	10 A.M.	Heavy swell	Easterly moderate
2	15th	9 36 A.M.	3 55 P.M.	9 45 A.M.	4 [illegible] P.M.	[illegible]	North west
3	16th	10 27 A.M.	4 19 P.M.	10 45 A.M.	4 P.M.	" "	Easterly and then westerly
4	19th	6 42 A.M.	6 43 A.M.	6 A.M.	7 45 A.M.	Calm	[illegible]
5	20th	1 16 A.M.	[illegible]	8 30 A.M.	8 45 A.M.	"	North east
6	21st	1 42 A.M.	7 5 A.M.	7 A.M.	9 A.M.	"	"

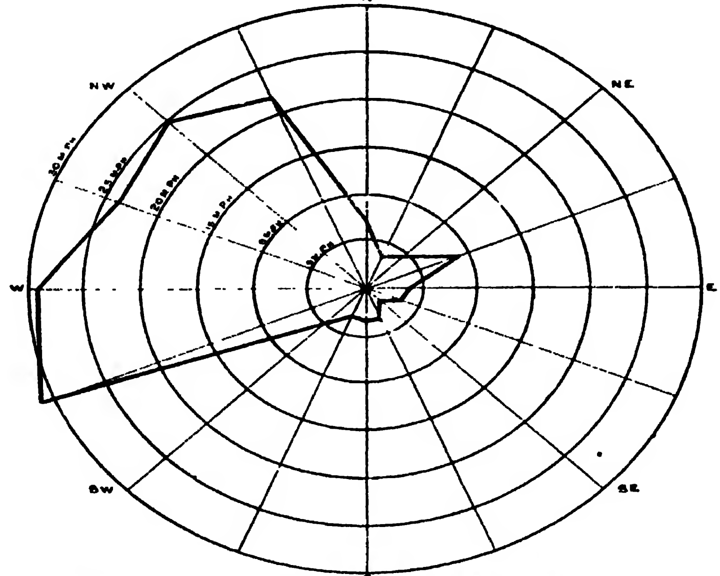


LOVE GROVE SEWAGE OUTFALL at the time of rising tide. Bright coloured part of the Sea shows area and direction of Sewage diffusion.



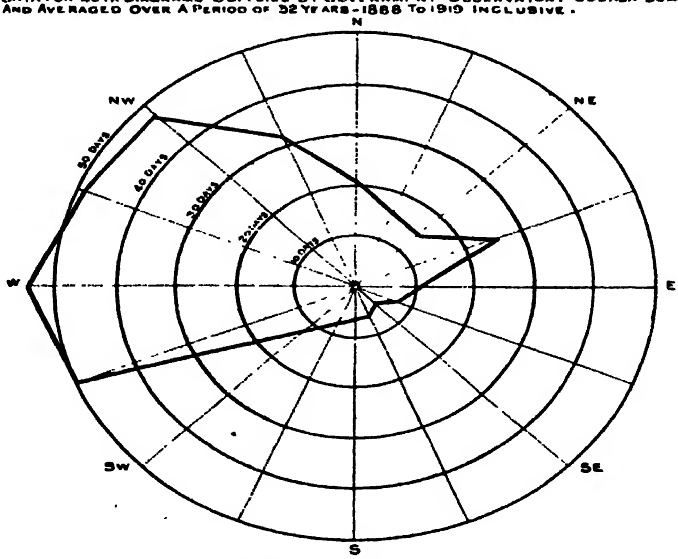
Same outfall at the time of Ebb-tide showing Sewage flowing along the Coast.

EMMANUELOV ON DRAINAGE PROBLEM OF BOMBAY.



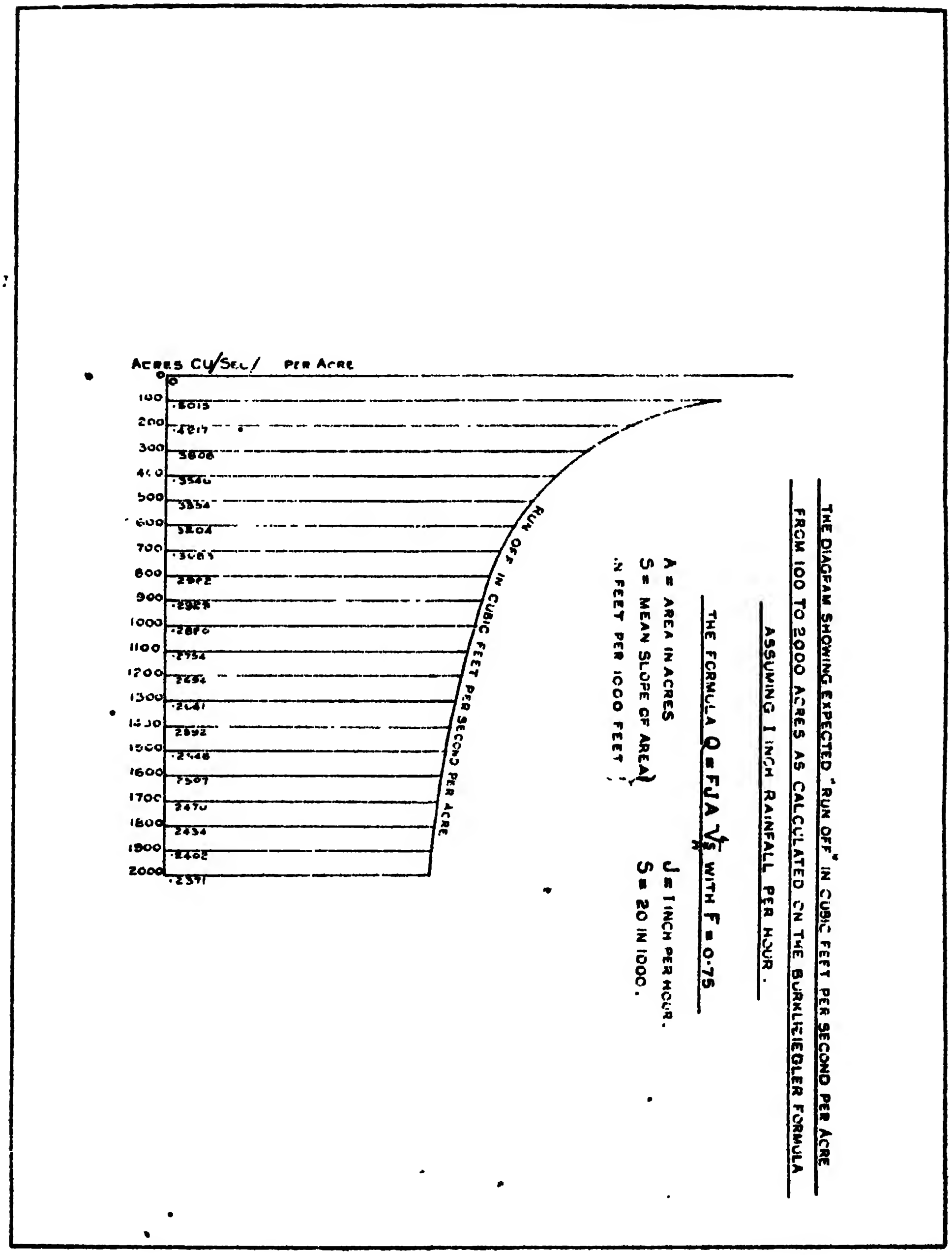
AVERAGE VELOCITIES OF WIND IN MILES PER HOUR

DATA FOR BOTH DIAGRAMS SUPPLIED BY GOVERNMENT OBSERVATORY COLABA BOMBAY AND AVERAGED OVER A PERIOD OF 32 YEARS - 1888 TO 1919 INCLUSIVE.

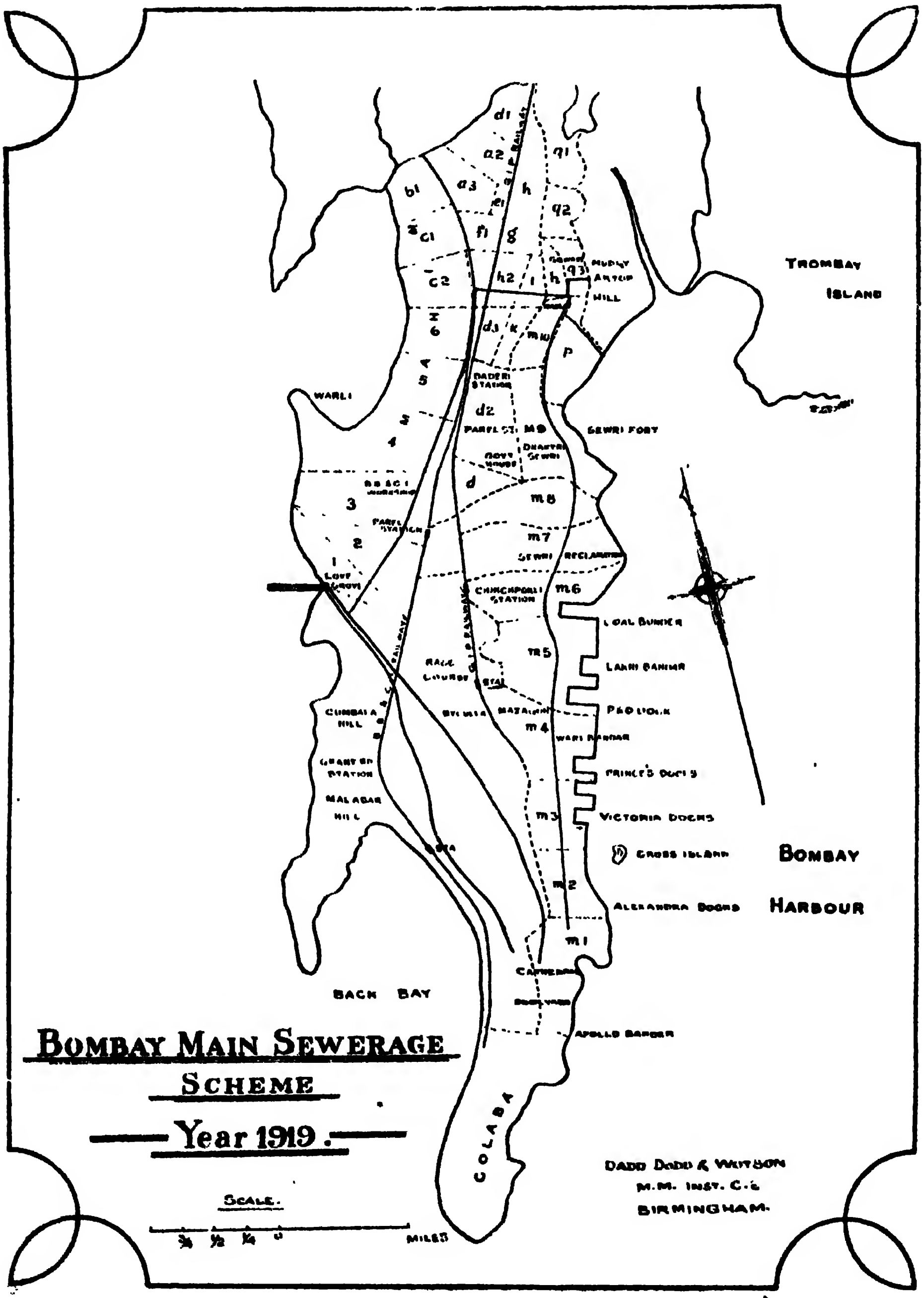


AVERAGE FREQUENCY OF WIND IN DAYS PER YEAR

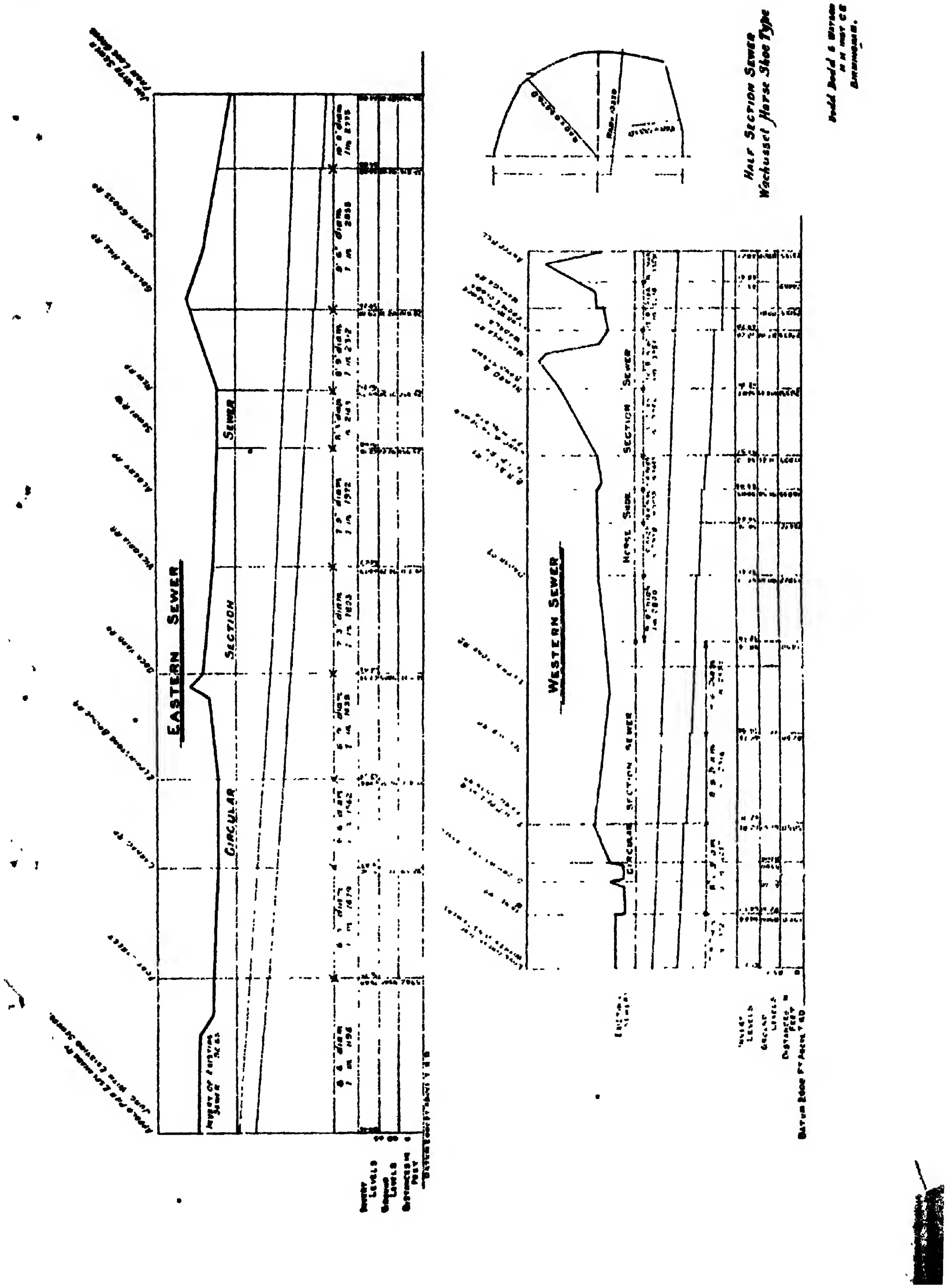
DODD DODD & WATSON
M.M INST. C.E
BIRMINGHAM

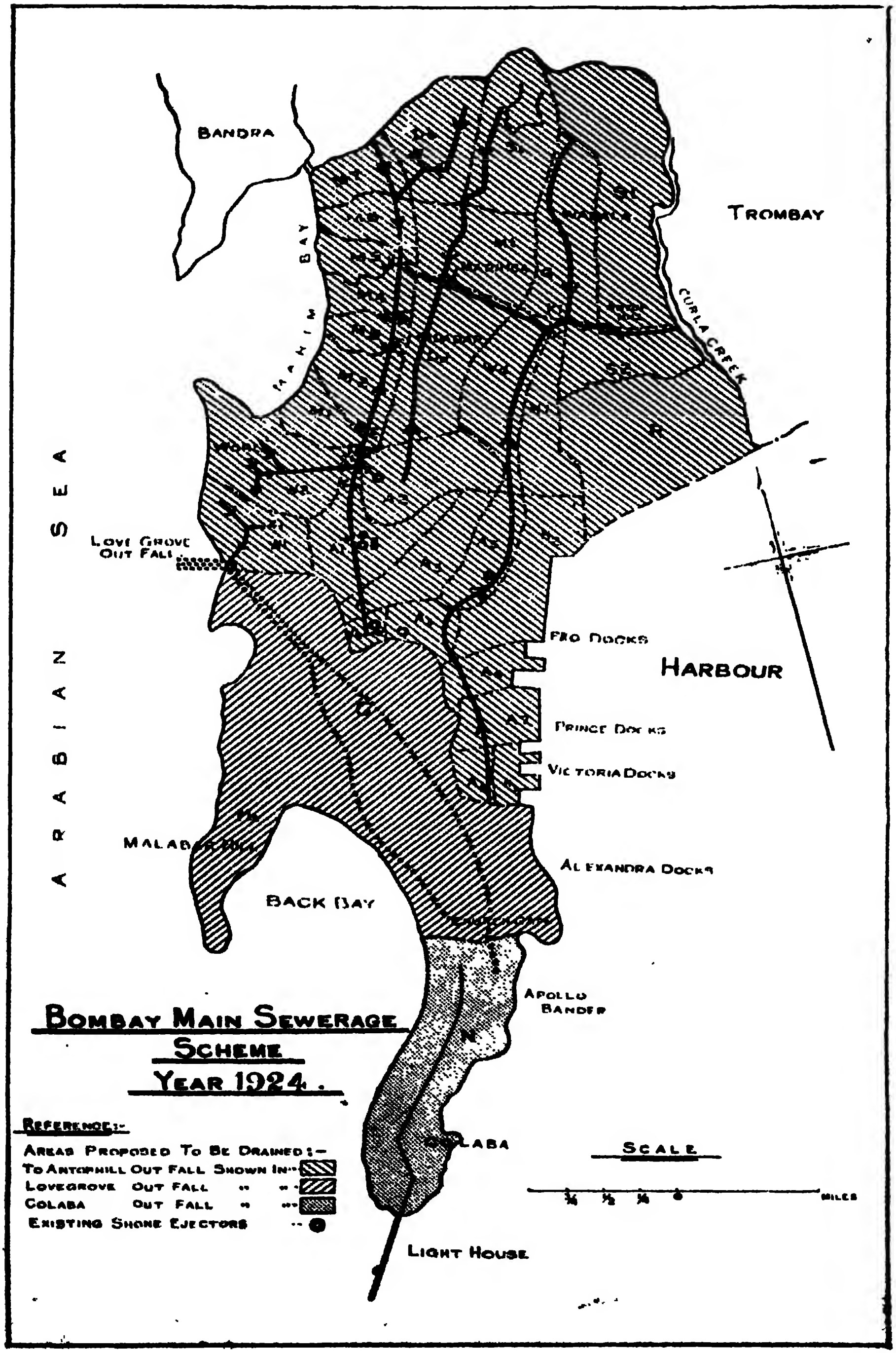


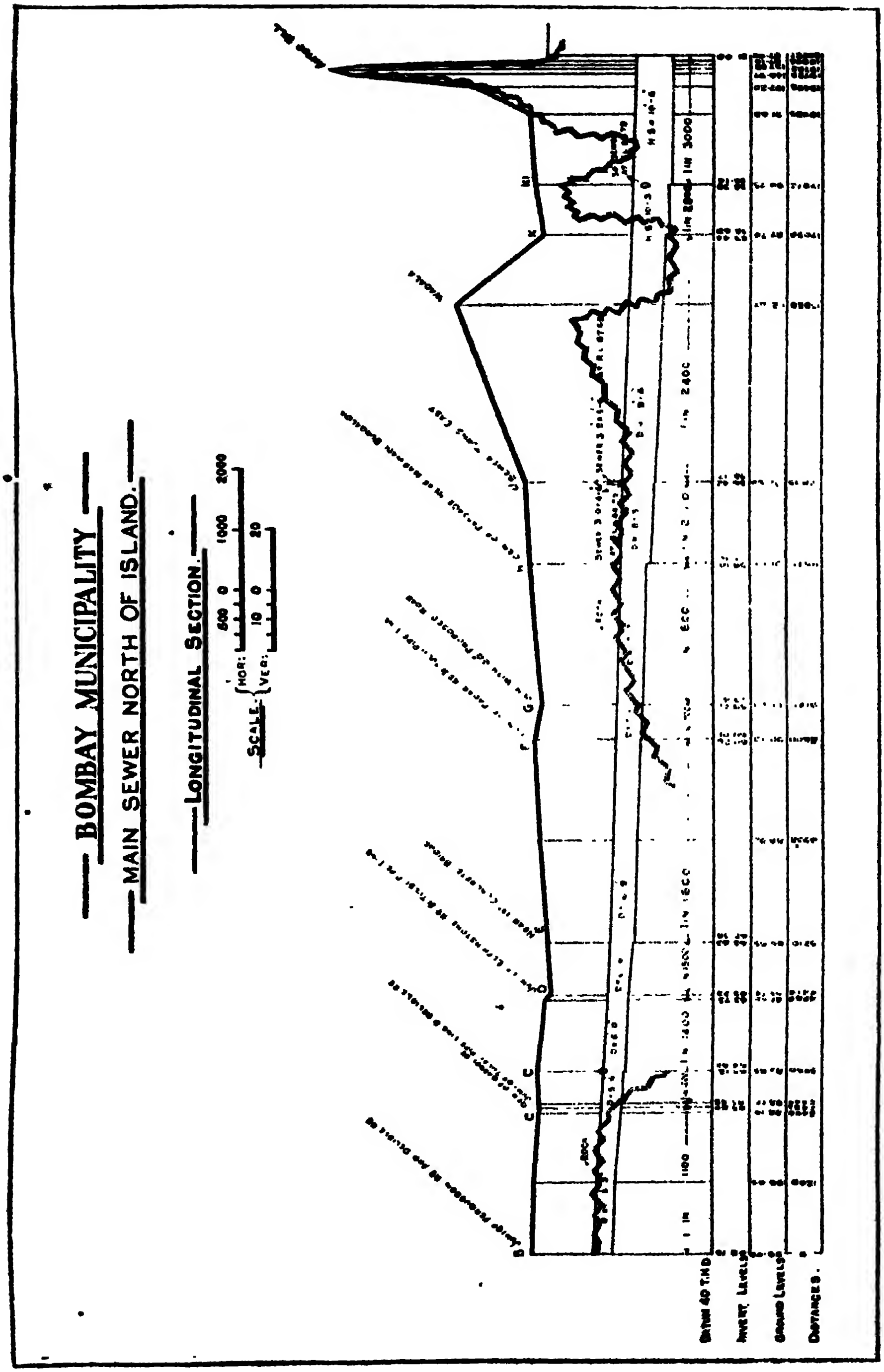
THE DIAGRAM SHOWING EXPECTED "RUN OFF" IN CUBIC FEET PER SECOND PER ACRE
FROM 100 TO 2000 ACRES AS CALCULATED ON THE BURKLI-ZIEGLER FORMULA
ASSUMING 1 INCH RAINFALL PER HOUR.
THE FORMULA Q = FJA $\sqrt[4]{\frac{S}{A}}$ WITH F = 0·75
A = AREA IN ACRES
J = 1 INCH PER HOUR.
S = MEAN SLOPE OF AREA IN FEET PER 1000 FEET
S = 20 IN 1000.
RUN OFF IN CUBIC FEET PER SECOND PER ACRE
ACRES
CU/SEC/ PER ACRE
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000


BOMBAY MAIN SEWERAGE
SCHEME
Year 1919.
SCALE.
MILES
TROMBAY
ISLAND
WARLI
SEWRI FORT
PAREL ST.
DADER STATION
CHINCHPOKLI STATION
CUMBALA HILL
GRANT RD STATION
MALABAR HILL
LOVE GROVE
COAL BUNDER
P&O DOCK
PRINCE'S DOCKS
VICTORIA DOCKS
CROSS ISLAND
BOMBAY
HARBOUR
ALEXANDRA DOCKS
APOLLO BANDER
BACK BAY
COLABA
DADD DODD & WATSON
M.M. INST. C.E.
BIRMINGHAM.

EMMANUELOV ON DRAINAGE PROBLEM OF BOMBAY.




BANDRA
TROMBAY
MAHIM BAY
CURLA CREEK
ARABIAN SEA
LOVE GROVE OUT FALL
HARBOUR
PRINCE DOCKS
VICTORIA DOCKS
MALABAR HILL
ALEXANDRA DOCKS
BACK BAY
APOLLO BANDER
COLABA
LIGHT HOUSE
SCALE
MILES
BOMBAY MAIN SEWERAGE SCHEME
YEAR 1924.
REFERENCE:-
AREAS PROPOSED TO BE DRAINED:-
TO ANTOPHILL OUT FALL SHOWN IN
LOVEGROVE OUT FALL
COLABA OUT FALL
EXISTING SHONE EJECTORS


BOMBAY MUNICIPALITY
MAIN SEWER NORTH OF ISLAND.
LONGITUDINAL SECTION.
SCALE. HOR: 500 0 1000 2000
VER: 10 0 20
DATUM 40 T.H.D.
INVERT LEVELS
GROUND LEVELS
DISTANCES.

DISCUSSION ON
THE DRAINAGE PROBLEM OF BOMBAY.

Mr. F. C. Temple remarked that the draining of a big town was a game played between those intent on doing it well, and those intent on spending as little as possible, or on safeguarding some private interest, in which the onlooker could not see most of the game because no study of reports could give full knowledge of the merits and defects of the scheme on the one hand, or of local politics and prejudices on the other.

To the onlooker at the Bombay drainage game however certain points were clear. The first and probably most serious was that the existing drains were put in when people knew too little how they should be built for Indian conditions. The next and almost equally serious was that too many people with insufficient knowledge to judge a scheme fairly were in a position to oppose with success any scheme that was put forward. And the next was that until Mr. J. W. Mackison's scheme, as blessed originally by Mr. J. D. Watson, or something very like it was installed, Bombay would never be satisfactorily drained. No scheme could possibly be satisfactory which failed to secure clean sewers. Silt traps and silt cleaning were mere palliatives, and would not eradicate the evils of the present system. Presumably many of the existing sewers would have to be relaid. Mr. Mackison's scheme appeared likely to make this relaying as inexpensive as possible. One smell at the Lovegrove Pumping Station would convince anybody with knowledge of sewage that the first necessity was to bring the sewage there so quickly that it could not have time to turn septic on the way. This could only be done by extensive relaying. It was not clear from the paper whether such relaying was contemplated for the area now draining to Lovegrove. But whatever was done, it should be such that this would ultimately be possible. The intercepting sewer proposed by Mr. Mackison to intercept the two main sewers at present gravitating to Lovegrove appeared to be some 12ft. lower than the existing sewers. If this was so, it was presumably so placed to permit of relaying the old sewers.

If the modification of the scheme proposed subsequently by Mr. Watson made this impossible, there would inevitably be disappointment and the ultimate cost to the town would be very

much greater. The periodical cleaning of the proposed impounding reservoir would create a greater aerial nuisance than had yet been met even at Lovegrove. Mr. F. C. Temple.

When the scheme was carried out it would be interesting to see if the provision for storm water as calculated per head of population proved correct. In India, the quantity to be dealt with in the sewer depended not as in England on the quantity of water that would come to them, but on the success with which it could be kept out. Careful arrangements for the exclusion of storm water might reduce the quantity which would enter the sewers to the equivalent of 1/20 inch of rainfall per hour run off from the whole area drained. According to Mr. Watson's report 11,657 acres were to be drained. At 1/20 inch per hour this represented about 370 million gallons per day which was a little less than Mr. Watson's estimate of 400 million gallons per day. To keep the volume down to 400 million gallons per day would need a very complete installation of effective storm water separators.

The estimate that only 32 million gallons a day would flow to Antop in the near future was likely to be over optimistic. Though it was true that a certain average relation had been established between population and storm flow in sewers, the storm flow would be there whether the population was or not, and as soon as the intercepting sewer had been constructed, the storm water was likely to fall into it.

The possibilities of purification of the sewage at Antop Hill by one of the bio aeration processes were almost unlimited. But the possibilities of disappointment were also almost unlimited. The sewages that had been so successfully treated in India by these processes were very fresh. Of the many difficulties that arose in working them one of the most frequent was that caused by some of the sewage going septic. The very septic sewage of Bombay was likely to prove very difficult, and the manurial value of the sludge from a septic sewage was liable to be lower than the value of the sludge from a fresh sewage. A comparatively small plant say one to deal with a million gallons per day should certainly be erected and worked for at least a year before a larger plant was designed.

MR. E. E. DESBRUSLAIS remarked that on page 159, "Fate of the Scheme" the author had shown clearly that, there was but one unsettled portion, giving rise to objections (viz.) the discharge of Sewage through the outfalls at Lovegrove; the other two outfalls at Prongs Light House near Colaba, and that into the Kurla Creek (after special treatment) from Antop Hill being accepted in 1926 by Government. Mr. E. Desbrus

The most natural question would be asked: why not treat the Sewage proposed to be disposed off as crude through the Lovegrove outfall,—either at Antop Hill and then dispose of it into the Kurla Creek?—the cost probably being the same as that proposed to be disposed off at Antop Hill as one of the three disposal points of the Sewage; or when treated at Antop Hill by the activated sludge process, the resulting innocuous effluent could be discharged at the Lovegrove outfalls? The latter would seem to cost more than the former proposal.

For treatment by the activated sludge process at Antop Hill of 194 million gallons of sewage per day under Monsoon conditions was shown to cost 12 million rupees. If the cost of the treatment was shown separate from the disposal, better results could be obtained and so he was compelled to take the figure as a whole. The Lovegrove outfall was shown to deal with 158 million gallons of Sewage maximum or about 2/3 of that of the quantity for Antop Hill or say 10 million rupees, and for the Colaba outfall 48 million gallons or ¼ of that of Antop Hill, i.e., costing 3 million rupees. The total cost would seem to be 12+10+3=25 million rupees or within 30 million rupees as originally estimated.

What a pity that the original scheme prepared by Mr. Mackison was not given effect to in toto, with the extra work involved by the inclusion of the activated sludge process even if this were to raise the cost considerably, since the scheme was one that embraced all the needs not only of to-day, but also of a distant future. Mr. Watson and Mr. Clayton said "that the scheme as designed, if given effect to would result in a successful and permanent solution of the Bombay sewage and drainage problems."

One more point which did not seem clear would be found on page 161 second para. viz., "and the outfall with 2 additional 6′ dia. barrels for a length of 2000ft." From page 135 it would appear that at Lovegrove there were already "two 6′ dia. Steel Barrels projecting into the sea for a distance of about 2000ft." and again on page 139 "only during short periods of the flowing tides does it (Crude Sewage at Lovegrove) flow sufficiently far out into the open sea and there thoroughly diffuse itself in the large volume of water."

From this it would appear that the sewage was carried out about 2000 feet outwards horizontally by pipes from the shore. Would any good result from pumping the sewage down into the sea water and letting it thus break up and spread it its way up wards through a good depth of sea water? Would this help in quicker and better surrounding of the crude sewage by the sea water and its movement caused by forced pumping?

Mr. G. Bransby Williams remarked that the drainage problem of Bombay required solution as urgently as that of Calcutta. In both cases the chief difficulty was that of the outfall. In Calcutta, what was originally a comparatively satisfactory outlet for the city sewage, had been allowed to deteriorate until the necessity for finding some other method of disposing of it had become acute. In Bombay the position originally selected for the discharge was obviously open to strong objection, but the difficulty of discovering any other outfall that had not been opposed on practical or sentimental grounds, had led to the nuisance created being continued in an ever-growing intensity, whilst the progress of the city drainage works had been retarded to a deplorable extent. Mr. G. Bransby Williams.

Mr. Emmanuelov's paper consisted for the most part of a history of the drainage system, an account of its defects, and a description of the data on which the new scheme had been prepared. A comparatively brief space was devoted to an outline of the scheme, which apparently was drawn up by Mr. Mackison and approved by Mr. Watson; and the alternative project subsequently prepared by Mr. Watson was cursorily dismissed in a few lines. The paper appeared to a considerable extent to consist of quotations from Mr. Watson's reports but how far this was the case was not made clear.

On the basis of such information as was supplied in the paper it was not possible to make any reasoned criticism of either Mr. Mackison's scheme or Mr. Watson's alternative, but certain points suggested themselves. In the first scheme the main features were two large intercepting sewers, one of which formed a continuation of the Lovegrove outfall sewer. These were to be very deep—from 40 to 50 feet at the low end. Apparently a good deal of expense would be saved by pumping all the sewage of the southern part of the city at Lovegrove into a high level sewer commencing at this point, and it was not evident why this arrangement was not adopted.

The remarks on page 134 of the paper regarding catchpits represented an ideal state of affairs entirely divorced from practical conditions. It was not possible to dispense with catchpits in any ordinary Indian sewerage system. The huts lived in by a large number of the inhabitants were of such a poverty stricken character that the cost of providing separate connexions to each holding from the sewers would in many cases be more than the value of the premises. The most that could be done was to provide for one connexion to a gulley serving a group of dwellings or a bustee. It

r. B. esbry

r. G. ransby illiams.

followed that sullage must flow for some distance in open drains. The amount of silt and garbage that was collected from these drains was remarkable. It was absolutely essential to intercept as much as possible of this, before it reached the sewers and the only way to do so was to construct gulley catchpits of considerable capacity. These catchpits did not have any effect on malaria. In the first place they silt up so rapidly that they had to be cleaned out every day or two, so there was no time for mosquitoes to breed in them. Even if they were left untouched for long enough for mosquitoes to breed, no anopheles would be produced for these would not breed in dirty water. Culex would breed if they got a chance but of course these did not carry the malaria parasite.

It was interesting to hear that 50 gallons of water per head was considered adequate to meet the needs of Bombay, when Calcutta was supposed to require more than double that quantity. The assumption that the sewage was equal to the water supply, which was usually made in England, did not hold good for the ordinary Indian town. In these the sewage was sometimes less than half the water supply in the dry weather.

The method of calculating the maximum run off in the storm-water drains did not appear to be very logical. Apparently whenever the maximum rainfall in a year had been over 2 inches, that year had been disregarded under the impression that no other fall occurred in that year over 1.52 inches. Moreover to take the average of a certain number of selected maximum rainfalls seemed a crude and unscientific system of calculation.

Obviously to design the branch drains in a town with the rainfall of Bombay on the basis of a rainfall of 1 inch per hour would result in frequent flooding. Rain might fall for short periods with an intensity of 10 times that figure and such falls were in fact by no means infrequent. The diagram of run off in his opinion showed too little run off for the smaller areas and too much for the larger. He should consider a reasonable allowance of run off for Bombay somewhat as follows:

0—10	acres	1½	inches	per	hour
10—50	,,	1	,,	,,	,,
50—100	,,	¾	,,	,,	
100—500	,,	½	,,	,,	
500—1000	,,	⅓	,,	,,	
1000—1500	,,	¼	,,	,,	
1500—2000	,,	1/5	,,	,,	
over—2000	,,	1/6	,,	,,	

The proposal to make the velocity of flow in the sewer $3\frac{1}{2}$ feet per second was an ideal which it was impossible to reach in Indian towns in the plains except at a prohibitive expense. In his schemes he provided for a daily dry weather velocity of 3 feet per second if possible, but in any case not less than $2\frac{3}{4}$ feet per second. Sewers designed on this basis had been perfectly satisfactory and there had been no trouble with silting of the sewers. Mr. G. Bransby Williams.

The statement on page 152 of the paper that the Bombay sewage contained twice the quantity of solids usually found in European sewage was misleading. In sewage disposal it was the solids in suspension that alone need be considered, and it appeared from the statement on page 151 that these were less in Bombay than in Europe.

Generally the impression created by the paper was that Mr. Watson had been compelled by force of circumstances to abandon the scheme he wished to carry out in favour of a cheaper and less effective scheme which perpetuated the nuisance of Lovegrove. The most interesting feature of the latter scheme was the proposal to treat the sewage of the northern part of Bombay by the Activated Sludge system. As regards that Bombay would probably be able to obtain some useful information when the experiment which he was carrying out for the Nagpur Municipality had been completed.

The paper ended up in a pessimistic vein and did not give any clear indication that anything at all was likely to be done to solve the Bombay problem in the near future.

Mr. M. Ahsan Zeman said it was unfortunate that the author was not present at the discussion. Anyhow his paper was very interesting. It gave a complete history of the Bombay Drainage and the opinion of the numerous experts consulted from time to time. In the paper sufficient details were not given for a complete solution of the existing trouble. One had to be guided by what the author had stated and an opinion formed on general principles. This was he believed the object of the author in presenting his paper. Mr. M. Ahsan Zeman.

The various Outfalls mentioned by the author and Mr. Modak were :—

(*a*) Lovegrove.

(*b*) Colaba Point.

(*c*) Worlee—do—

(*d*) Mahim Bay.

(*e*) Green Isle.

(*f*) **Kurla Creek.**

(*a*) The Lovegrove Outfall had been a complete failure.

(*b*) An Outfall at Colaba point which would have been the very best could not be had now as it was too late to reverse the whole system.

(*c*) Worlee Point was no doubt better than Lovegrove in as much as there was more space available for the construction of purification works but it would not be a permanent solution of the problem and whenever the sewage was not purified to the extent necessary there would be the same nuisance again. Moreover the cost of purification would be very heavy with practically no return. The idea of adopting the Worlee Outfall was again the same make-shift policy of the past which would result in enormous capital cost and no return or permanent benefits.

(*d*) Mahim Bay had more or less the same defects as Worlee and was rejected for the same reasons.

(*e* & *f*) Green Isle and Kurla Creek were both on the Eastern side of the Island. Here there would be no accumulation of Sewage along the shore owing to the favourable currents but the Port Trust would not allow untreated sewage to be discharged into the harbour. Hence it seemed that purification must be resorted to on the Western side to get over the objections raised by the Port Trust. If the Outfall was to be at Worlee the cost of purification and maintenance would be much more than at Antop Hill. The space being limited mechanical methods of purification must be adopted such as the Activated sludge with heavy capital and maintenance cost, while at Antop Hill a large area was available which could easily be acquired and reclaimed for the construction of detritus chambers and simple sedimentation tanks.

The Sludge could be disposed of as pointed out by the author and the effluent, instead of being discharged into the harbour and wasted could be pumped on to the Trombay Island close by. Thus the sewage need only be partially purified at a comparatively low cost and a fairly large income obtained from the resulting effluent.

This was proposed by Major Tulloch so far back as 1871 but, as the author had stated, Mr. Pedder the then Municipal Commissioner interfered and nullified Major Tulloch's proposals by doing away, particularly, with the scheme of application of Sewage to land.

There was enough experience now as to the results of sewage disposal by Broad Irrigation in India and the revenue to be expected. In Poona the revenue from the effluent alone was about Rs. 100 to 110 per acre apart from the water rate.

Mr. M. Abs. Zoman.

From the test given by the author there was no doubt that the sewage of Bombay was very weak and did not require much fresh water for its dilution before giving it out for irrigation.

It might be stated here that for Effluent Irrigation to be profitable and successful a certain amount of fresh water was also needed for variable periods according to the kind of crops grown.

As he was not acquainted with the conditions in Trombay Island he could not say what possibilities there were for securing a reliable fresh water supply for Irrigation. With a heavy rainfall he thought it would be possible to arrange for fresh water either by a storage reservoir or tube wells.

However, the proposal seemed to be a very paying one if investigation showed that land and fresh water supply could be economically arranged.

An approximate idea of the income could be had from the following figures. Taking the future population to be 2 millions, the area of land required would be about 10,000 acres and discharge of sewage effluent would be about 185 cusecs in the dry weather which was enough for irrigating about 10,000 acres. With a charge of Rs. 100/- per acre the income would be 1 million or 10 lakhs. Moreover according to the author an income of about 3.7 lakhs might be expected from sludge valued at Rs. 60/- per ton. He was not quite sure about this as the sludge from sedimentation or septic tanks was not of much value. It might be utilised for manuring and reclaiming the Municipal Farms at Deonor as proposed.

After carefully considering the history of the case and the various objections of the Port Trust and Government it seemed advisable and economical to adopt the Antop Hill Outfall as it had been decided to have the Sewage purified before discharging it into the sea.

Finally he was of opinion that the complete Scheme proposed by Mr. Watson should be adopted at once doing away entirely with the Outfalls at Colaba and Lovegrove and not the compromised scheme of Mr. Watson, as the author called it, which retained the Lovegrove and Colaba Outfalls.

STORM WATER DRAINS.

Mr. Watson and the author were perfectly right in stating that the condition of the Storm Water Drains was deplorable. They were a menace to the health of a large city like Bombay and it seemed disgraceful to have such a state of affairs continue for years when huge sums were being spent on water supply, housing

Ahsan and building up new suburbs, etc. More than half the trouble at Lovegrove was due to the open Storm Water Channels. One could not imagine that in a city like Bombay large open kutcha channels and open reservoirs were allowed.

The contributory drains as stated by the author were also in a deplorable condition. The catchpit and the trap for intercepting grit must be entirely removed. It seemed very strange to spend lakhs on remedial measures for malaria and yet allow innumerable sceptic catchpits for convenient breeding of mosquitoes all over the city. The principle cause of malaria being endemic in Bombay was the filthy condition of the storm water connections and Outlets.

In nearly all large cities in India the problem of the Storm Water Drains was left in abeyance till the very last, simply because it was thought that much nuisance could not be caused by Storm Water. Really speaking in large cities the road sweepings consisting of house refuse and animal excreta and litter from stables etc., were being daily put into the Storm Water Drains. Also, effluent from private septic tanks without any land treatment was allowed to flow. In some cases sewage connections had been wrongly made and in many cases the sullage was made to flow into the Storm Water Drains. All these practices contributed to infect the small volume of liquid flowing or stagnating in the Storm Drains in the dry weather. In Bombay the rainfall was not uniform right through the year. It was well known that the Storm Drains were not flushed except in the monsoon or after an extraordinary heavy shower. With obstructed outlets the putrified liquid accumulated in them under tide locked condition forming long authorized septic tanks.

If an entirely separate system was to be retained and improved at an enormous outlay of 3 crores it seemed absolutely essential that the Storm Water Drains must be remodelled and improved first. No open drains or reservoirs were to be allowed. If tide locked conditions were produced the Storm Water should be disposed of in a similar way to sewage by collecting it in covered reservoirs and pumping it into the sea at all tidal conditions.

In his opinion if satisfactory results were to be attained the Storm Water Drains should be reconstructed and maintained on sanitary lines along with the new Sewerage Scheme. The principles to be laid down should be :—

(*a*) No open drains were to be permitted under any circumstances.

(*b*) Direct falls into the sea should be provided as far as possible.

(*c*) In case of tide locked conditions covered reserviors should be designed for the storage and the liquid pumped daily into the sea. Mr M. A Zeman.

(*d*) As street sweepings, animal droppings and sullage from cattle sheds, etc. were washed into the Storm Drains, the discharge generally contained putrifactive organisms. In the dry weather there would be generally a very small flow in the drains, in fact the solids would settle on the invert and obstruct the flow. Hence if no catchpits or gulleys were to be permitted, in future it would be necessary to flush these drains daily and keep them quite clean.

(*e*) All drains should be of such a form as to be able to carry the flow in the dry weather with a self cleansing velocity. In the case of large drains the invert should consist of a central channel of a smaller diameter either of S. W. pipe or concrete with the sides sloping towards the channel with 1 in 3; more or less similar to the invert of the Lancaster type or a cunette section may be adopted in case of very large sewers. All smaller sewers should be of ovoid section new form and the smallest drain should not be less than 18" × 27".

(*f*) An entirely separate system was to be rigidly enforced and no connexions whatsoever were to be allowed between the Sewage and Storm Drains; the partially separate system now practised was always open to abuse in some form or other and must be stopped.

(*g*) The main features of the proposals for the new Storm Water Drainage as pointed out by the author should be adhered to.

Finally he would add again that more than half the trouble and nuisance at present was due to the faulty Storm Water Drains and storm Outfalls. In any scheme which was to result in a successful and permanent solution of the problem the question of Storm Water Drains should receive the first and formost considera-tion.

CAPACITY OF SEWERS.

To estimate correctly the capacity to be provided was very nearly impossible. Rate of water supply and quantity of ground water were really the only data from which an approximate figure might be arrived at. The daily rate of water supply for a city like Bombay should in future be not less than 50 gallons per capita. In fact it was sure to increase to 75 gallons per capita in the next few decades.

Ahsan

For the present assuming that only 50 gallons per capita per day reached the sewers, the average flow per hour would be $\frac{50}{24}=2{\cdot}08$ gallons per head per hour; but as consumption of water fluctuated throughout the 24 hours the quantity of sewage would also vary. In fact, practically 80% would reach the sewers in 6 hours; that was to say the maximum rate of flow would be $\frac{40}{6}=6{\cdot}67$ gallons per head per hour or nearly 3·2 times the average flow. This did not provide for any factor of safety which should be at least $1\frac{1}{4}$ times; adding this the capacity should be 8·34 gallons per head per hour or very nearly 200 gallons per capita per day.

In a city like Bombay where the rain fall was heavy and the position was rather low, a great deal of ground water might be expected. This should not be mixed up with the storm water which in the case under discussion was to be entirely excluded. Under very favourable conditions as to nature of soil, elevation and dry weather the quantities of ground water varied from 10 to 15 thousand gallons per mile while the maximum might be more than 100 thousand gallons per mile.

As stated in the paper under discussion 15 thousand gallons per mile was very low. In his opinion in Bombay the allowance should be at least 30 thousand gallons per mile.

It might be mentioned here that in American cities the provision for ground water (sub soil water and not leakage from water supply) usually varied from 15 to 150 gallons per head. Compared to this in Bombay there should be a provision of at least 20 gallons per head as the conditions were not very favourable and a great deal of sub soil water was met with. According to Falwell the maximum capacity of the sewer to be provided is $(50+20)\times 175\% = 122{\cdot}5$ gallons per head. As a further safeguard he recommended a factor of safety of 2 to $1\frac{1}{2}$ for small and large sewers. Hence for small sewers the capacity to be provided is 245 gallons per head and for large sewers 184 gallons per head. While for large trunk sewers the capacity could safely be about 150 gallons per head.

With the above considerations Mr. Watson was quite right in providing the capacity at 200 gallons per head, for large and small sewers.

In case of the trunk sewers, however, the capacity must be reduced to 150 gallons per head.

He did not agree with Mr. Watson that overflows should be provided to discharge sewage direct into the sea without treatment

in the monsoon. This would cause a nuisance again. The best method was to exclude rain water entirely and carry the full discharge of sewage to the disposal works without providing any overflows, catchpits or balancing tanks. Mr M. Ahsa Zeman.

In sewerage and water supply schemes it was always wise to provide more capacity than required, as there were so many considerations and contingencies. In the case of sewerage, silting and erosion of the invert usually resulted while in water supply corrosion and reduction of mains was always occurring. Also judicious and careful selection of co-efficients of Rugosity was very necessary, as otherwise one might be providing for adequate capacities but calculated with wrong co-efficients which ultimately resulted in much less provision. From the conditions of sewers during construction and the lack of maintenance in future, he thought the following should be the co-efficients of Rugosity.

1. S. W. Salt Glazed pipes. $n = 0{\cdot}013$ to $0{\cdot}015$
2. Cement plaster or Glazed brick inverts. $n = 0{\cdot}015$ to $0{\cdot}017$

It was found in India that S.W. Pipe drains had many defects regarding, clean joints, true alignment and bearing, hence theoretical conditions were not fulfilled in practice and the coefficients of Rugosity should be as above. In case of glazed brick inverts, the brick joints in actual construction were ¼" to ½" thick and were generally rough and uneven, with the result that the conditions became quite different. In fact in some cases he had found that the surface instead of being quite smooth had become corrugated with the numerous brick joints. Actually a cement plastered surface was better than the glazed brick surface provided it was not eroded and damaged. Hence with a view to proper future provision, the suitable co efficients would be as indicated above. The capacity should always be calculated with the worst conditions and not assuming the best workmanship and conditions.

A few words might be said as to the suitable shapes of sewers for Bombay. The minimum size of a sewer for Bombay should be 9" diameter. S.W. Pipes, ought to be used for drains 9" to 18" diameter and cement concrete circular pipes for sewers 21" to 60" diameter. Above 60" diameter egg shape or ovoid sewers (new form) should be adopted with glazed brick inverts and lining up to 2/3 of the depth, the largest size to be not more than 8' × 12'. After this the cunette section Washington type should be used with a semi-circular concrete arch and half-round cunette, the ledges on the sides sloping 1 in 6. In the Washington type the cunette portion and the side ledges up to the D.W.F. level need only be lined with glazed bricks.

SELF CLEANSING VELOCITIES.

Mr M. Ahsan Usman.

He agreed with the author and Mr. Watson that the velocities with the D.W.F. discharge should be self cleansing. For Indian conditions this velocity should not be less than 3′ per second—in case of large sewers, and 3½′ per second—in case of small sewers up to 12″ diameter. When pumping was adopted it should not be difficult to obtain these velocities.

No tables of discharges drawn up according to English practice were suitable to the Indian conditions. It was always safer to calculate using Kutters formula with the values of n. as mentioned above.

Silting was the trouble in all the Indian systems. It was also due to the habits of the people who used earth in closets and for washing utensils. Hence if future failures were to be avoided the principles for self cleansing velocities should be enforced rigorously and if in any rare case the velocity fell below the minimum fixed, automatic flushing syphons should be provided of sufficient capacity to flush the drains regularly at intervals, thus keeping them quite clean.

CONCLUSIONS.

(1) That the Antop Hill Outfall was the most suitable and should be insisted upon.

(2) With the self cleansing velocities proposed it was expected that the sewage would reach the plant in a fairly fresh condition and hence it could be pumped direct for irrigation without any further treatment. The amount of rest in the pump chamber would not be more than half an hour. This was actually being done in Poona, with very good results and if handled properly the same system could be followed provided fresh water was available on the Island for diluting and distributing the liquid for irrigation. In case the Sewage arrived in a stale condition it would be necessary to adopt a simple sedimentation process providing a rest of say 3 to 4 hours and then pumping the effluent.

He was against the Activated sludge system as it had not been tried in India on a large scale and the capital and maintenance costs were very heavy.

(3) The small and large sewers should be designed to carry 200 gallons per head per day and the main trunk sewers 150 gallons per head per day.

(4) The co-efficient of Rugosity in Kutters formula should be 0·13 to 0·15 for S.W. Pipes and 0·15 to 0·17 for cement plaster or glazed brick sewers. Mr. M. Ahsa Zeman.

(5) Storm Water should be entirely excluded from the sewers by not allowing any surface drain from houses or overflows to be connected with the sewers.

THE AUTHOR said in reply:—referring to Mr. Temple's remarks on his paper, and particularly to that place where he stated that until Mr. Mackison's scheme, as blessed originally by Mr. Watson, or something very like it, was installed, Bombay would never be satisfactorily drained, the author said that he was glad that his views on the Bombay Drainage Problem had been endorsed by so prominent and well known Sanitary Engineer in India as Mr. Temple. But most unfortunately the Bombay Municipal Corporation were accepting other views and by agreeing to the modified scheme of 1924, necessitating the retention of Lovegrove Outfall, were continuing their usual policy of palliatives involving unnecessary expenditure to the extent of over Rs. 32 lacs. This was to be spent on the problematic experiment in trying to eliminate the existing nuisance produced by this Outfall condemned by all experts whose opinion had been sought on many occasions. Therefore one could not but agree with Mr. Temple's remarks that "the drainage of a big town like Bombay was a game played between those intent on draining it well, and those intent on spending as little as possible" and that "too many people with insufficient knowledge to judge a scheme fairly were in a position to oppose with success any scheme that was put forward." The septic action that was usually taking place at present in Bombay sewage received at Lovegrove was caused partly by the flat gradients and sinuous routes of the existing sewers in certain parts of the city and still in a major degree was due to a very inefficient pumping arrangemenfs at Lovegrove which continuously retarded sewage flow in two main trunk sewers and backed it up to not less than 4 to 5 feet height thus considerably reducing velocity of flow in the main as well as in certain subsidiary sewers. With the adoption of Mr. Mackison's original scheme providing abolition of Lovegrove Pumping Station and substituting it by a gravitation sewer to Antop Hill it was hoped that the condition of flow in the existing sewers would be improved to a certain extent, but relaying of certain old subsidiary sewers in the city was certainly inevitable. As regards the sewers already laid recently in the northern unsewered part of the Island and those which it was proposed to lay there in connection with the Antop Hill scheme they were all designed with velocities of not less than 3 *ft.* per sec. and along The Author

The Author. the shortest possible routes, so that there would not be the slightest chance of the flowing sewage in them being turned septic before reaching the proposed purification works at Antop Hill.

The provision for the storm waters at the time of monsoon in the newly designed sewers had been made to the extent of four times their D.W.F., which had been based solely on the observations made with the existing sewerage system of Bombay and considered adequate to meet monsoon "run off" requirements in the condition of an Indian town like Bombay.

It was true that in India the quantity of rainwater to be dealt with in the sewers depended on the success with which it could be kept out. For success there would not be so much need of very complete installations of effective storm water separators, as of well trained sanitary engineers, capable of understanding those ideas and able to enforce their application by subordinates.

It was a matter of fact that in Indian conditions, and in the cities like Calcutta or Bombay in ninety out of a hundred cases even most important sewer and storm water connections were being made under the supervision of an ordinary mistry, a person with very little knowledge of sanitary principles. Therefore it was not surprising at all that many sewers in the city were connected with storm water drains and *vice versa*.

He had seen himself such extraordinary connections, as when three-9 inches and two 15 inches pipes were found joined into one 15 inch pipe.

It was also a common fact that in the cities like Calcutta and Bombay, with the old drainage and sewerage systems no proper records had been maintained not only of all the connections made, but even of all the existing drains and sewers in the city, thus giving sometimes opportunities to the mistry to make wrong connection he having no data as to whether it was a sewer or S.W. drain.

It was difficult to argue with regard to the volume of sewage expected to be received during the monsoon at Antop Hill during the first few years, estimated in the present case by Mr. Watson to be about 32,000,000 gallons per day, as this volume would solely depend on what subsidiary sewers would be laid within the period of those years. Looking at the slow rate at which population of that part of the city was being increased and the number of sewers provisionally laid there within the last few years there was very little hope that anything more than one-sixth of the total area of that part of the city would be sewered within that time. At the

same time considerable progress had been already made in that part of the city in providing drains for the removal of storm water, which gave a certain amount of assurance that only the minimum possible amount of rain water would fall into the intercepting as well as subsidiary sewers in that locality. The Author

Passing on the question of the proposed sewage purification at Antop Hill on the Activated Sludge process he agreed with Mr. Temple that there would be certain difficulties to be experienced in treating the septic sewage of Bombay as it was now, but it was confidently expected that with the introduction of the proposed measures already described above, considerable improvements in the sewage flow would be attained thus diminishing septic process in the sewers so common in present condition of their flow. The Installation of a small experimental plant prior to the design of a larger plant was of course the most desirable course to be taken by the Bombay Municipality, but he was afraid the Corporation was not willing to adopt this course of action as it involved a certain amount of expenses on the experiment.

Passing on to the comments made by Mr. Bransby Williams he would like to point out that he had written his paper with the object mainly of drawing the attention of Engineers to most undesirable but very common practices in India of dealing with the most important schemes, vitally affecting the interests of millions of populations, in a manner as described in his paper. The second object that he had in view was a desire to enable young Engineers engaged on Sanitation in India to get acquainted with certain data based on nearly a century of experience with the Bombay drainage and possibly common to any other similar drainage scheme to be undertaken in India, where it might be of certain use in one or other respects.

He had no intention, as well as no space available in his paper, to go into the technical details of the two proposed alternative schemes, as suggested by Mr. Bransby Williams. Nevertheless there were still sufficient data given in his paper to see that with the retention of Lovegrove Outfall, as contemplated by the last scheme of 1924, the drainage problem of Bombay would remain unsolved. Being engaged during seven years of his service with the Bombay Municipality on the drainage works of Bombay and being personally connected with the preparation of the modified scheme, as proposed by Mr. Watson in 1924, he had a certain amount of personal experience in the matters described in his paper, though his views might be similar to those entertained by Mr. Watson himself. Nevertheless whenever Mr. Watson's opinion had been quoted in his paper it had been always so mentioned.

As regards Mr. Bransby Williams' opinion that a good deal of expense would be saved by pumping all the sewage from Lovegrove into a high level sewer to Antop Hill, it must be pointed out that this was not the case, the necessity of constructing another equally large intercepting sewer in the same direction but at a slightly lower level would certainly involve more expense than if only one large gravitating sewer was laid instead of two. Besides that the existence of a high level sewer involved maintenance of the pumping station at Lovegrove for the lift of sewage to be delivered to Antop Hill, which was not desirable for the reasons already mentioned and which became quite unnecessary if one gravitation sewer was constructed.

The only advantage of such a high level sewer would be a small saving in the height of the lift of sewage at the Pumping Station at Antop Hill by about 10 ft. only, which was negligible in comparison with the expenses involved by the maintenance of two pumping stations, at Lovegrove and at Antop Hill, and by the construction of two large sewers instead of one.

Mr. Bransby Williams had evidently misunderstood his remark about the undesirability of catchpits which referred to the storm water entrances usually provided along the streets to intercept grit and metal carried with the road washings, and not to the gully catchpits in the sewers that were provided to intercept silt and garbage flowing along with sewage and which Mr. Bransby Williams considered indispensable in Indian condition at any rate. But in spite of this he was equally against provision of such catchpits in both cases and particularly in Indian conditions, where putrifactive process of the organic matter, intercepted in such catchpits, was very rapid on account of the high temperature of the Indian climate. They were equally unnecessary arrangements serving no purpose if the sewers or storm water drains were designed and built with sufficient velocities and able to carry the whole detritus to the point of outfall. To recognise their necessity was in his opinion equivalent to recognition of a privy Basket System because in both cases collection of decomposing matter and carriage along the streets was equally inevitable, while this work was a legitimate duty of every properly designed system of drains.

He equally disagreed with the ideas that those catchpits did not have any effect on malaria and suggested a reference to the opinion of malaria experts investigating this disease in Bombay or Calcutta and to any weekly reports published by the Health Department of the Bombay Municipality, on several occasions registering cases when anopheles had been found breeding in these

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catchpits. If this was not the case there would be no necessity of sprinkling them with kerosine oil, as was being done by the Bombay Municipality, though he was sorry to say in certain cases only.

It was true that these cases were confined only to the central part of the city, just to show that something was being done in that direction, while 80% of the total number of the city's water entrances had their catchpit not only never oiled but very seldom even cleaned.

To confirm his opinion on the subject of catchpit necessity he would refer to the report of the Metropolitan Sewage Commission, New York, 1924, stating that "the catch-basins were in reality among the most useless devices employed for the removal of solid material from sewage. They were generally infective because they were not cleaned with sufficient frequency to enable them to serve as traps. It seemed impracticable to keep them clean. To maintain catch basins in serviceable condition required much hand labour, and this was costly. The work was usually carried out to the annoyance of pedestrians and householders." Another report to the Commissioners of Sewage of Louisville by J. B. F. Breed and H. P. Eddy, 1913, stated that "it was felt that in this climate it was unwise to provide pools of water in which mosquitos could breed as is the case where catch basins are built."

A more or less scientific method of calculation in determining the rate of maximum rainfall that should govern the choice of the storm water drain sizes could only be made if the rainfall intensity as well as its duration, which was the most essential factor, had been recorded by automatic rainguages and during comparatively a long period of years. In the absence of Bombay data, the determination of the rate of rainfall that could safely be taken without exceeding the critical economical basis in the design of proposed storm water drains was certainly a matter of opinion of the engineers concerned and as such was certainly open to criticism. But the practical knowledge of conditions in Bombay showed that a rainfall of over one inch per hour intensity was confined usually to comparatively small and certain districts only and last for a very short period, measured in minutes, which condition would affect small branch and subsidiary drains and not the large conduits. Therefore a rainfall of 1 inch per hour intensity had been considered as sufficient for areas to be served, provided certain allowance was made in calculation of "Run off" for the small areas.

Besides that another allowance had to be taken into consideration by adopting Kutter's formula for calculations of storm water

The Author. flow in drains, when somewhat lower results in calculation of flow in small pipes were usually obtained, as compared with the actual results.

Though in the chapter of his paper dealing with the "run off" reference had been made to Buzkli-Zeigler's formula only, it was due to his oversight that the actual data upon which all calculations of the Bombay storm water drainage were made in the present case had been omitted.

Those data were as follows :—

Area in acres. Small areas.	*The flow as calculated on the basis of 1 inch per hour reduced by No reduction.*
100—200	... ... 5%
200—400	... ... 10%
400—600	... ... 15%
600—800	... ... 20%
800—1000	... ... 25%
Over—1000	... ... 30%

He did not consider that the statement made on the page 152 of his paper that the sewage of Bombay contained twice the quantity of solids usually found in European sewage was misleading as it had been made only to indicate the causes of so easy silting at the inverts in sewers in India and not with reference to the disposal of sewage in which case solids in suspension had alone to be considered. The results of the experiments with the Activated Sludge process that were being carried out by Mr. Bransby Williams for Nagpur Municipality would be certainly of much interest to Sanitary Engineers in India and would be eagerly awaited with a hope that an interesting paper on this subject would be read before the Institution of Engineers (India) in due course.

Referring to the remarks made by Mr. Desbruslais he had to point out that the question of diverting sewage from Lovegrove to Antop Hill and discharging it into Kurla Creek after preliminary treatment at Antop Hill was quite a natural question and this had been provided in Mr. Mackison's original scheme. But as this involved a certain amount of extra expenditure on the construction of a larger size trunk sewer from Lovegrove to Antop Hill as compared with the trunk sewer if the sewage from the north part of the island alone was to be carried to Antop Hill, the Municipal Corporation turned down this scheme for the sake of economy. Besides the treatment of nearly double the amount of sewage on the Activated Sludge process at Antop Hill in this case would certainly involve double the initial expenses as well as the in-

creased cost of maintenance so that the Municipality evidently preferred to perpetuate the existing nuisance at Lovegrove Outfall by discharging crude sewage there than to spend a few lacks of rupees extra and so solve the drainage problem for ever. The Author

The method of calculation in obtaining rough cost of sewage treatment on the Activated Sludge process if the whole sewage of the city was brought to Antop Hill was not correct, as the estimated cost of Rs. 12,000,000 for the work at Antop Hill included not only the cost of treatment work, but also the cost of construction of large trunk sewers as well as the Pumping Station, etc. But the cost of the purification work installation alone at Antop Hill had been roughly estimated at that time to be about Rs. 37 lakhs which was already included in the estimated cost of Rs. 12,000,000 for Antop Hill.

Mr. Desbruslais was not quite correct in assuming that the sewage at Lovegrove was being carried out horizontally to the sea by two 6 feet diameter barrels of the Outfall, as those barrels were laid to a distance of about 2000 feet from the shore at the bottom of the sea and with a maximum possible gradient, thus allowing sewage to flow to the open sea to a distance equal to the length of the outfall and then to raise up from the bottom to the sea surface when sea water level was sufficiently high. But the whole question was that the sea was not sufficiently deep along this coast of Bombay and the variations of the tides were as high as follows :—

	Feet T.H.D.
High Water, extraordinary spring tides	88·42
,, ,, ordinary	86·25
Mean High Water	84·50
High Water, ordinary neap tides ...	83·24
Highest low water	81·00
Mean sea level	80·16
Low water, ordinary neap tides ...	77·25
Mean low water	76·00
Low water, ordinary spring tides ...	74·25
Mean lowest water, ordinary spring tides	72·00
Low water, extreme tides	71·16

which gave extreme variations of the tides equal to 17·26 feet.

At the same time the top level of the 6 feet dia. steel barrels of the outfall at their extreme end in the sea was about THD—74·00 there was not sufficient depth of sea water to cover the mouth of the outfall during certain periods and left the outfall entirely exposed at other periods.